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Real Time Information into the Cockpit: A Conceptual Overview

Benjamin W. Bishop

Master of Aerospace Engineering

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Abstract

This investigation discusses several issues pertaining to the distribution of Real time Information into the Cockpit (RTIC). Specifically, attention is focused on the vision of this new technology and how it applies to the United States Air Force. The concept is defined and discussed as it applies the Air Force's core competencies. The attributes characterizing "push" versus "pull" architectures are also depicted. In addition, the supporting grid, which will be the foundation of these new technologies, is reviewed. In particular, the requirements and current limitations of implementing the grid are discussed. Finally, the process of implementing an RTIC process in an operational context is outlined. The data collection, fusion, and dissemination phases are analyzed against the backdrop of a U-2 to F-16 sensor-to-shooter scenario.

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Glossary

BPSK Binary Phase Shift Keying

CRT Cathode Ray Tube

DF Data Fusion

FOV Field of View

HDD Heads Down Display

HMD Helmet-Mounted Display

HUD Heads Up Display

IFOV Instantaneous Field of View

JDAM Joint Direct Attack Munition

JTIDS Joint Tactical Information Distribution System

JDL Joint Directors of Laboratories

MMI Man-Machine Interface

NPG Network Participation group

PPLI Precise Participant Location and Identification

QPSK Quaternary Phase Shift Keying

RTIC Real Time Information into the Cockpit

RTOC Real Time Information out of the cockpit

SA Situational Awareness

SAM Surface to Air Missile

STARLink Satellite Telemetry and Return Link

TADIL Tactical Digital Information Link

TDMA Time Division Multiple Access

TDRS Tracking Data and Relay Satellite

TFOV Total Field of View

UAV Unmanned Aerial Vehicles

1. Introduction

The battlefield of tomorrow is not the battlefield of Desert Storm. With every passing day it takes on a new shape as advances in technology progress at an exponential rate. The investigation Joint Vision 2010 was undertaken to address this issue under the context of joint operations. The study revealed the evermore-obvious notion that the conflict of tomorrow will be as much as a battle for information as it will be for land, sea or air control. Thus, the warfighter who has ability to control information and distribute it on demand will hold a decisive edge on the battlefield of tomorrow.

It is this insight that has lead the United States to develop technology that enables the communication of advanced Real time Information Into of the Cockpit (RTIC). Enhanced Aircrew situational awareness, operational flexibility and increased mission effectiveness against fleeting targets are all goals achievable through the implementation of sensor-to-shooter RTIC technologies. [1] Although there are numerous RTIC topics worthy of discussion, a complete analysis would not be possible in the confines of this investigation. Therefore, this paper will focus on a few central themes that describe the RTIC concept and illustrate how the process will proceed in an operational sensor-to-shooter context.

The first topic of discussion will be the vision of RTIC technologies. A brief investigation on the definition of RTIC will be preformed. This seemingly trivial examination is necessary to provide insight on the meaning of the topic and to specify the objects of this investigation. Next an examination of the United States Air Force's core competencies is made. How these goals are supported by RTIC innovations is key to understanding why such technologies must be pursued. In addition, a quick but

discerning examination will be made on some of the characteristics that distinguish a true RTIC system from conventional means of information management. Finally, a brief look is taken at one main design trade in an establishing a sensor-to-shooter system. Whether data should be "pushed" or "pulled" in an RTIC network is a major design decision that will be made as these technologies are integrated into the armed forces.

Next, the supporting information grid that will provide the foundation of all RTIC systems will be reviewed. A descriptive overview of potential grid capabilities is made. In addition, an outline of the grid's requirements is presented. These provisions will need to be met for the grid to effectively support the warfighters in need. The current limitations of implementing the grid is also a facet that is explored. These limitations will need to be overcome if the full potential of sensor-to-shooter technologies is to be reached.

Finally, a brief overview of the sensor-to-shooter process will be made. The initial collection phase of the sensor-to-shooter loop will be the first stage profiled. The methods in which the sensors are integrated into the information grid and what future capabilities are expected is presented. The data fusion phase follows with an insight on the importance of the information sorting process. How the information is distributed to the warfighters in need is then summarized. These three phases are discussed in the context of a typical sensor-to-shooter loop that passes information from a U-2 reconnaissance aircraft to an F-16 pilot on a strike mission.

2. The Concept

Before a technical investigation may be made into the concepts enabling real time information to be supplied in the cockpit, it is important to discuss the meaning of the concepts themselves. Only with an understanding of the definition, vision, characteristics and design considerations of RTIC technologies can an appreciation of the process itself be obtained.

2.1 RTIC Defined

Defining the terms that identify the RTIC concept is a task that must be performed in order to grasp the concepts of this investigation. The true meaning of "real time" as it applies to information transfer in the battle arena is the first term that must be settled. Real time can be inferred to represent a diverse number of concepts. However, in the context of this investigation, information transferred in "real time" is sent quickly enough to be received and assimilated in time to make a difference. Information received in "real time" must reach the warfighter in time for it to processed by the user and still be of applicable use. For instance, an F-16 pilot who receives intelligence regarding a SAM threat range upon returning for the mission did not get the information in "real time." Nonetheless, the second pilot who runs through the SAM range who uses the information for a follow on sortie will indeed have that information in "Real time" even though the mission may take place several hours later. So indeed, the issue of "Real time" is not necessarily how fast information can be distributed, but instead one of how information can be distributed in time enough to be of use.[2]

Next one must look at the meaning of "Information" in the context of RTIC. Webster describes information as "*knowledge communicated or received concerning a particular fact or circumstance; news.*" [3] Alas, Webster's insight can be directly applied to the issue of which we are investigating. "Information" can be deemed as any intelligence pertaining to the warfighter's mission on hand. Included in this spectrum are target images, ancillary satellite data, navigation information, and even a cautionary word from a wingman. One must note however, that even though data may be deemed information, its communication to the user is not necessarily a benefit to the mission. A wingman that constantly babbles is not conducive to a pilot's chance of mission success. Even though the wingman may occasionally communicate useful information, the pilot will tune them out and the pertinent knowledge will not be assimilated. This same occurrence will transpire whenever information of any type is presented to the user in an overwhelming manner. This condition, known as information overload, must be avoided at all costs.

The term "into" also holds meaning that must be examined. Under context of this investigation, "into" primarily represents information flowing to the warfighter's cockpit. However, in a true RTIC system, critical information will be flowing out of the cockpit as well. Real time Information Out of the Cockpit (RTOC) will be a vital source of intelligence that will be utilized in the future. Instantaneous bomb damage assessment will be possible by relaying real time imageries back to battle management centers. This knowledge will be a force multiplier by enabling the battlefield commanders to better apply available forces.

Finally, the word "Cockpit" must be discussed to establish what the term represents in a sensor-to-shooter context. Traditionally one envisions a cockpit as a compartment in which the controller of an aircraft is seated. Yet, when contemplating issues of RTIC, a broader implication of the term must be inferred. A cockpit can be considered a satellite ground station, the inside of a tank, the guidance system of a JDAM, as well as a pilot's "duty office." Indeed, a cockpit may be considered any warfighter or military system that needs information in real time to enhance mission accomplishment. Information essential to a warfighter can be sent into either one of these environments in real time.[4]

In summary, the concept of real time information into the cockpit can be defined as such: *The transfer of information to warfighters in need quickly enough for the intelligence to be received and assimilated in time to effect the warfighter's actions in a manner conducive to mission success.* This definition is key to understanding the RTIC concepts that the warfighter will employ.

2.2 The Vision

With the terms of RTIC defined, it is noteworthy to investigate the visionary future of these concepts in the United States Air Force. An examination of the Air Force's core competencies provides understanding in how these developing technologies support the vision of blue suiters. Air and Space Superiority; Information Superiority; Global Attack; Precision Engagement; Rapid Global Mobility; and Agile Combat Support – All objectives of the 21st century Air Force. [5]

Air and Space Superiority can be characterized as obtaining control of the entire vertical spectrum above the ground, thus maintaining complete dominance of the skies over the battlefield. Air and Space Superiority is the foundation on which all operational concepts are based in achieving *Full Spectrum Dominance.*[6] The concepts of enabling RTIC technology are founded on establishing Air and Space Superiority. One who holds the high ground of superior information will have an upper hand in future air and space control. The ability to quickly and effectively collect, process and distribute information is becoming evermore important with technological advances. Obtaining command of Air and Space on a battlefield is a crucial time-critical mission. The need to detect, identify, and engage rapidly moving targets requires a rapid response of sensors, shooters and command and control. [7] These abilities are only achievable through RTIC technologies

Information Superiority is identified as the ability to collect, control, defend and exploit information while preventing an enemy from doing likewise. Battlefield success is built on the framework of superior knowledge. In future battles the goal of Full Spectrum Dominance requires a pure interactive battlespace picture. These pictures will be provided by implementing real time sensor to shooter technologies.[8]

Global Attack is the ability to attack quickly anywhere and anytime. A network of forward-deployed and rapidly deployable forces is what enables a global attack capability. [9] A robust and effective information grid supporting these forces is essential to optimally achieve a global attack capacity. As described later, this grid will be established and networked using an RTIC framework.

Rapid Global Mobility enables an unsurpassed ability to provide global reach to the nation.[10] Unlike Global Attack, Rapid Global Mobility builds a bridge from airlift and aerial refueling quickly and decisively. The coordination of forces required for such a task is immense. The transportation of aircraft and resource information via RTIC technologies provides the framework upon which a Rapid Global Mobility mission can be constructed. For instance, aerial refueling must be optimized to provide for the most efficient and timely bridge for cargo aircraft. The battle manager can continually observe KC-135 aircraft using an information grid established with RTIC technology. Current fuel levels, GPS locations and crew status information can be continuously inserted into the information grid. This provides mission flexibility and reliability that will prevent any aircraft from attempting to gas up on an empty KC-135. [11]

Precision Engagement is the ability to provide selective force against particular targets.[12] Future conflicts will increasingly require the capability to apply military force with a minimal risk and collateral damage. Performing such a task requires a global awareness capability that enables precise targeting and supports national decision making.[13] Only through the continuous input of worldwide sensors can a global awareness be achieved. An RTIC information grid is the means by which this infrastructure can be established.

Agile Combat Support enables combat commanders to improve the responsiveness, deployability, and sustainability of their forces. The efficiency and flexibility provided by Agile Combat Support is intended to rely on responsiveness instead of massive

deployed inventories. [14] Employing a time-definite resupply strategy that begins on arrival will reduce the initial and overall lift requirement. Commanders will reach back to the continental United States for delivery of an item in need. The ability to know the location of critical parts, no matter which Service or agency holds the parts, is a huge and essential task.[15] The utilization of RTIC technologies and will provide such information to be inserted into the universal information grid. Thus, the logistical managers and battlefield commanders can have the precise and necessary information presented on demand.

2.3 Characteristics of RTIC Systems

In addition to investigating the definition and vision of RTIC sensor-to-shooter systems, it is also pertinent to discuss some attributes that characterize real time military information distribution systems. RTIC systems are designed to be parallel, fast, and dynamic. This is in stark contrast to the current serial, slow and nonresponsive architecture that is currently employed. [16] The prevailing "stovepipe" systems of information communication constrain the ability to transport useful information to the warfighters that need it the most. It is these characteristics that enable RTIC technologies to meet the visions of the 21st century.

Parallel: Information processing systems that operate in parallel are inherently quicker and more effective that those that function in a serial manner. Serial processors handle information packets independently and thus, numerous bottlenecks quickly mount. Parallel systems in contrast, enable multiple input and output paths of information that

can be processed simultaneously. A parallel information communication system will be able to process multiple sensors data sources and concurrently distribute requested data to warfighters. Just as parallel computers can outperform their serial counterparts, advanced RTIC systems will render the current information infrastructures obsolete.

Fast: As mentioned above, there is not a specific information transfer rate that characterizes a RTIC system. Nonetheless, speed is still a common attribute of RTIC systems and the speed is fast. To successfully transmit sensory information in real time to warfighters executing a time-critical mission, rapid networking speeds are required. RTIC systems are designed to incorporate parallel processing and advanced technologies to ensure that the user is supplied with information in real time. These design considerations result in RTIC systems that are intrinsically more efficient and faster than conventional stovepipe infrastructures.

Dynamic: Probably the most distinguishing characteristic of RTIC systems is their inherent ability to be flexible and dynamic. In conventional stovepipe systems, sensory data had to be passed up the information "chain-of-command," transferred to the warfighter's organization and then back down to the warfighter, thus the term stovepipe. A true RTIC system abolishes this process through the use of a universal information grid that will be discussed in more depth later in this investigation.

2.3. Information "Push" versus "Pull"

Besides discussing characteristics of RTIC systems, it is also notable to briefly examine a major design trade in establishing a sensor-to-shooter infrastructure. Specifically, the decision to either "push" or "pull" information into the cockpit must be settled. "Pushing" data is characterized by the process of sending information without a user request. This method can simplify the information flow process by using external algorithms to determine what category of information the user requires. Therefore, instead of having to wait for a user request, the information deemed important can be relayed immediately upon arrival. This approach may seem appealing, especially to those who must design the data flow architecture. However, this methodology has a major flaw – it disregards operator judgement. Imagine every time an email was received on a personal computer the CPU stopped all functions and displayed the email. Users would quickly become disgruntled after they lost twenty pages of work on a word processor. Under an information "push" style, the same problem can occur in a cockpit. The best source of judgement on which information is needed is the operator at hand. A pilot only wants to be offered information that he or she deems necessary. With the ever-increasing sources of data, the issue of information overload is of critical importance. An information "push" RTIC infrastructure has inherent dangers of exceeding the information overload envelope.[17]

On the other hand, in an information "pull" system, data is not presented to the user until a user request is sent. Thus, instead of constantly receiving information, both useful and worthless, the operator is only provided information upon demand. This request can be performed in several different manners. For instance, the request could be

instantaneous and spontaneous. A pilot may need the weather conditions of a region to which he or she has been diverted. The request could also be integrated into the mission planning stage. For example, the pilot may need SAM threat ranges displayed at 50 nautical miles of their approach. Finally, the pilot may want any information considered critical automatically presented. An obvious example of this would be the instance of a SAM launch in the pilot's vicinity. Although the forms of information request vary, one central theme remains consistent – the user's judgment is considered. Thus, by only presenting information the pilot regards meaningful, the issues of information overload become more manageable.

3. The Supporting Grid

To accomplish the goals discussed above a full information network-of-networks must be established that includes advanced information processing, storage, discerning information management and complete communications connectivity. [18] This infrastructure known as "The Grid" will be the foundation that enables real time information to be collected, fused and dispersed to the warfighters in need. The concept of the grid is the revolutionary step forward that will forever change the way battlefield information is procured and utilized.

3.1 Grid Capabilities

The grid is comprised of more than just an elaborate communications network. Indeed, reliable and efficient communications must be secured, however, it will be a mere part of system-of-systems that will create an entire "information environment."[19] Processing, information reservoirs, and services to enable the users to locate, exchange and fuse information will all be incorporated into the grid. [20] Warfighters will access the grid at anytime from anyplace to pull the information needed. By selecting services and interfaces pertinent to their mission, users will craft their own personal information environment. Hence, grid will provide unprecedented connectivity enabling warfighters to adapt their information needs according to the ever-changing battlefield.

The grid infrastructure will entail diverse communication links, satellite networks, airborne relays, fiber optic links and tactical radios. [21] Management centers will facilitate the diffusion of information, maintain operations and ensure system security. This network-of-networks will be orchestrated much like the network-centric computing

system which is now commonplace. As software advances such as the Hyper Text Markup Language (HTML), and the Java computing architecture enabled computers with different operating systems to communicate, advances in communications architecture will enable the exchange of sensor data between warfighters independent of the platform upon which they operate.[22]

Initially the grid will combine current networks and processing centers to institute an integrated information environment. This first step will bridge existing systems of the military branches and provide the foundation on which the grid is to be established. Near term additions will include automated capabilities that assist in the management of information and the end-to-end throughputs. Integrated management will be key in harnessing the true potential of the grid in its infancy and unlocking the power of the knowledge contained within it.

However as the grid continues to grow, the inherent problem of information overload become more of an issue. To combat this problem "learning" computers designed with neural networks will serve as invaluable intelligent agents. These systems will be able to learn and identify trends in the sensorial array of data. This ability will forever change the way a battle is fought and managed. For instance, a neural network trained in the tactics of an adversary will have the ability to analyze all information on the grid pertaining to the enemy's force structure. Consequently, the system could very reliably predict future enemy maneuvers. In addition, these networks will be capable enough to detect deviations from doctrine, thereby alerting commanders of possible surprise attacks or deceptions.[23]

3.2 Requirements

Nonetheless, before the grid replaces our finest military generals, it will first have to meet specified requirements to support the common warfighter. In particular, the capability to be interoperable is essential for the grid to service both joint and coalition forces. Adaptability will be essential in servicing the eclectic alliances of tomorrow. It is impossible to predict the grid architecture required to support future operations. Thus, as information needs change, the grid will need to adapt and compensate in real time. In addition, to provide services to various coalition forces, language, culture, and military procedure translations will be required to occur within the vast grid infrastructure. This need will also have to be balanced with the high degree of security demanded on such vital information.[24]

The robustness and resiliency of the grid will also be critical to ensure the success of its operations. As with any military system, the grid will need to be able to operate in the harshest conditions and support any component of the military forces despite the environment. It must be able to not only defend itself from the elements, but also from the emerging threat of information warfare. Users must be confident that the services provided by the grid will be available when needed. Indeed, 100% cannot be achieved. Nonetheless, a level of confidence must be obtained that does not make the grid a weak link in the command, control and communications chain.[25] Warfighters also not only need assurance that the grid services will be provided when required, but also that the information provided is of sufficient integrity. Implementing the grid in such a manner as to allow the users to comprehend and trust the information is a difficult challenge that must be met.

3.3 Current Limitations

Today's armed forces are currently unable to provide the services necessary to support the grid architecture and capabilities discussed. A multitude of limitations currently exist that must be overcome if a true information grid is to be established. Presently, it is difficult to retrieve specific knowledge from a massive, grid information system.[26] This ability is crucial for real time information to be pulled by warfighters. As discussed before, a blue print for this type of operation currently functioning on the World Wide Web. However, the capacity to pull information from a vast information grid is not available to the modern day warfighter.

Another current limitation is in the ability to transport information in the command and control hierarchy. As mentioned before, information is currently conveyed in an inflexible stovepipe fashion that severely hinders the ability to establish quick reaction time networks needed within the grid. This rigid architecture restricts the ability to trade information among heterogeneous users. [27] As discussed above, flexibility is the attribute that will permit the grid to function under diverse conditions and with numerous different platforms. The inadequate communications in command in control will result in insufficient connectivity to tactical users attempting to utilize the services offered by the grid.

The inability to adequately secure the grid's infrastructure is also a severe limitation that must be overcome to bring these capabilities to the battlefield. Currently, there is a lack of sensors that can detect an information warfare attack on an information grid. The incapacity to detect such an assault on the grid greatly restrains the ability for it

to defend itself. In addition, anti-jam capabilities and robustness of services are in question. Without these defensive measures, there is a lack of confidence that the grid assets will be available when they are needed. Such unreliability is unacceptable in efficient military operations.

4. The Process

The actual process of transmitting information from sensors to the warfighter in real time can be partitioned into three main parts: data collection, data fusion, and data dissemination. Data collection involves utilizing ground, sea, air, and space sensors to accumulate information and transport it to a battle management center. There, the data fusion step occurs which compiles the data into pertinent user information. Finally, the information is distributed to the warfighter in the dissemination phase.[28] An in-depth analysis of either of these steps could in itself yield a massive investigation. Thus, in the interest of brevity only a few issues pertaining to the separate phases will be addressed. To aid in illustrating these phases a conceivable present day scenario will be discussed throughout this chapter. Specifically, an airborne U-2 will be diverted to collect visual image data of a reported SCUD missile launcher. This image will be relayed to battle managers, fused and distributed to F-16s on patrol who will be tasked to destroy the launcher.

4.1 Data Collection

The purpose of sensors is to provide warfighters with an augmented perception of situational awareness (SA). SA to the warfighter is basically knowing what's going on around them. Warfighters rely on situational information to navigate, evade, target and attack. Without it they are blind and incapable of performing the necessary missions. The initial phase of a sensor-to-shooter loop is designed to collect as much relevant information and provide it to a battle management center to be processed.

4.1.1 The Sensor Grid

Sensors take many forms. The original aircraft sensors were simply the pilot's own eyes and ears. They provided reliable information that guided the first airplanes and were quickly augmented with internal instruments such as attitude indicators and compasses. As technology advanced, radar, radio navigational aids and photoreconnaissance assisted pilots in their mission planning and execution. Today Forward Looking Infrared (FLIR), U2 reconnaissance planes, Unmanned Aerial Vehicles (UAVs), AWACs, RC-135 Rivet Joints, Joint STARS, space based reconnaissance platforms and numerous other sources of information serve as the new eyes and ears of the modern aviator.

As technology continues to expand, other non-traditional forms of sensors will begin to supply warfighters with intelligence. Acoustic sensors that can accurately detect tanks and other mobile vehicles will be accessible on the battlefield. In addition, olfactory sensors will be able to use "smell" to identify targets and gustatory sensors will "taste" them. One day, even tactile sensors will use radar to reach out and "touch" targets to reveal a target's shape, temperature and hardness.[29]

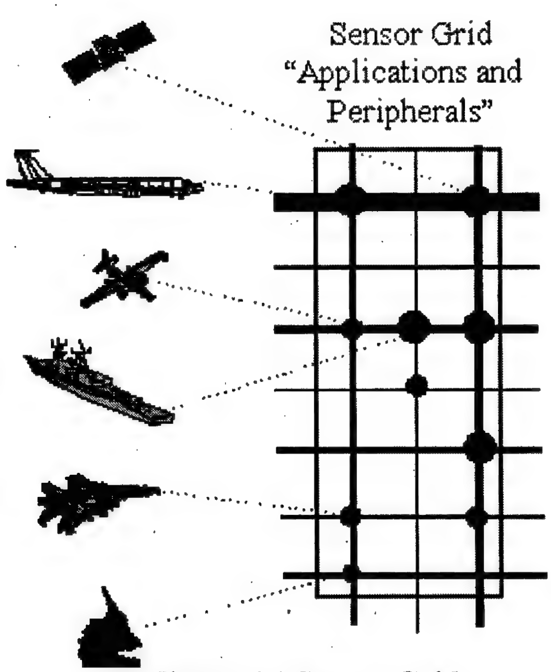

Figure 4.1 Sensor Grid

For now however, pilots rely on more conventional means of obtaining situational awareness. In an advanced RTIC system, collectors from air, space, land, sea and, even cyberspace will feed raw data into a subsidiary portion of the grid know as the "sensor grid." The sensor grid entails a

network of sensors that serve as peripherals on the information grid.[30] Just as various input devices interface with a typical desktop computer, diverse sensors groups will feed the grid with information on request. The sensor grid is connected to the main information grid through various communication links including line of sight microwave transmissions and satellite crosslinks. This interconnectivity is essential to providing flexibility that is crucial to an RTIC system. Instead of relying on one information path, sensory data can be distributed through numerous means via the information grid. Not only does this result in dynamic response, but also induces redundancy into the vital communications network.

Today a typical peripheral to the sensor grid the U-2 reconnaissance aircraft. Although an elaborate information grid is not yet established, many characteristics of an RTIC system are illustrated in a basic U-2 based sensor-to-shooter loop. A U-2's ability to receive real time commands induces a high degree of mission flexibility. As in the case in our scenario, an aircraft in route can be diverted to fly over mission critical regions to support in bound fighters. This is a attribute that enables to U-2 to be a highly effective data collector in the RTIC process.

As can be seen in Figure 4.2, the U-2 has an impressive means of collecting sensor information. To remain in concurrence with the presented scenario, this investigation will primarily focus on the acquisition of imagery data. Imagery data can be collected by digital cameras that produce typical data streams of about 100 Mbits per second. High caliber data of this nature is typical of the assets needed to assist a pilot in finding and making a positive identification of a target. This is especially true when the target is small and mobile as in the case of a SCUD launcher.

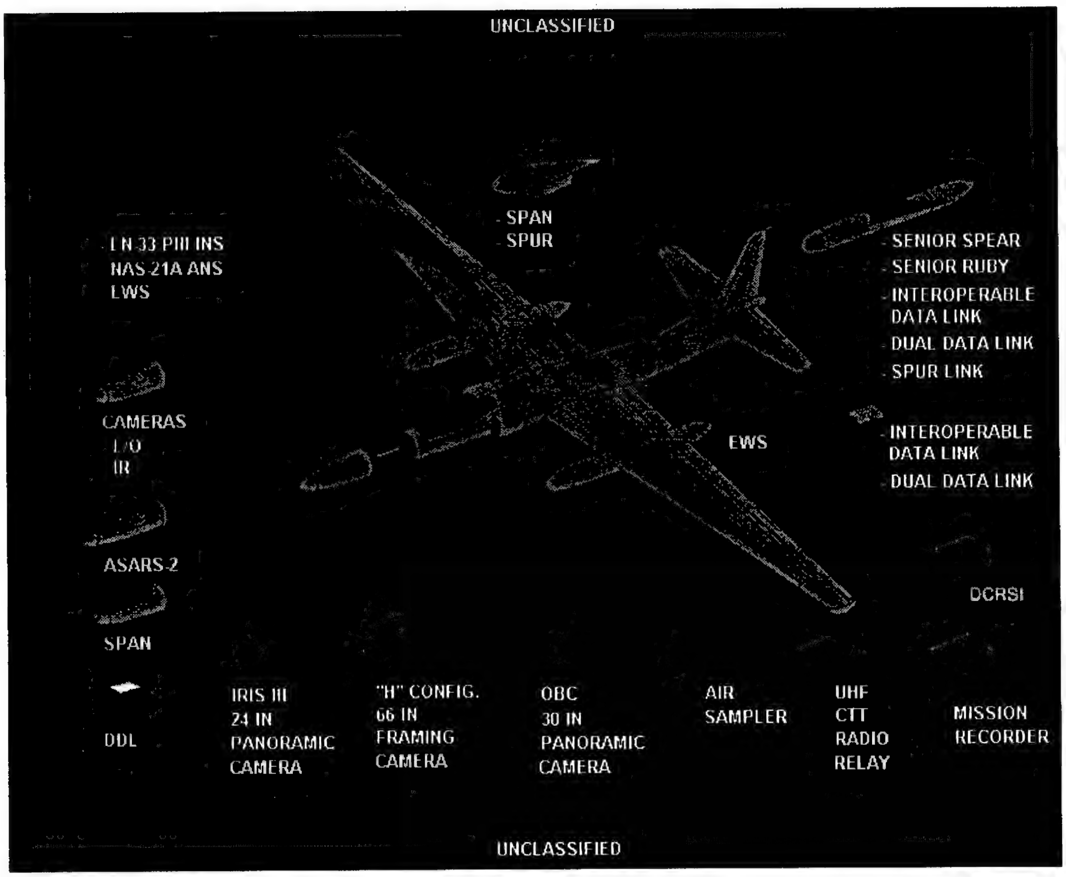

Figure 4.2 U-2 Payload

4.1.2 U-2 Communications

Reconnaissance information obtained by a U-2 aircraft is relayed to orbiting satellites using a SPUR or SPAN satellite communications system. These dorsal fin-like pods contain steerable antennas that can establish a real time communication link to the battle managers. For obvious security reasons, the functional details of these systems cannot be revealed. However, an analysis of the Satellite Telemetry and Return Link (STARLink) employed by NASA's ER-2 provides significant insight on how this process transpires. Illustrated in Figure 4.3, the ER-2 is a slightly modified U-2 that performs high altitude research missions for NASA. The STARLink communications system provides real time data flow from scientific experiments and enables highly interactive experiments to occur at the upper reaches of the earth's atmosphere. [31]

Command data may be sent to an ER-2 aircraft at a rate of 400 KBPS in nonreturn to zero level format via the TDRS satellite system. The forward link signal is transmitted to the aircraft at a frequency of 13.775 GHz with a Binary Phase Shift Keying modulation

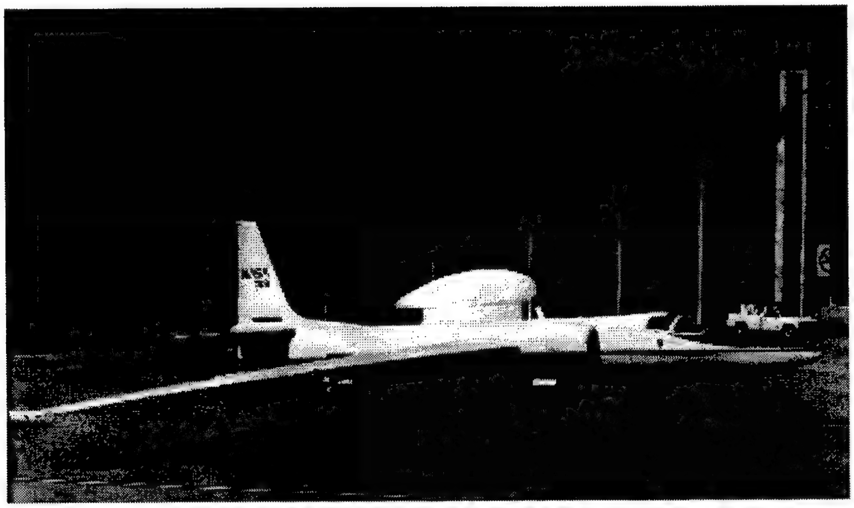

Figure 4.3 ER-2 Aircraft

scheme.[32] On an ER-2 mission these commands may be used to provide real time control of the experiment by modifying the control parameters. During a military U-2 mission these commands are the means that enable flexibility and enhance the ability to provide time critical information. Referring back to the SCUD scenario, it is this forward link that will enable battle managers to alter the course of the U-2 to fly over the potential SCUD location.

Although the forward command link provides needed flexibility to the U-2's mission, the return link is what provides the essential SCUD images needed in the F-16 cockpit. Collected data on the ER-2 is compressed and flows from the sensors to the transceiver at an intermediate frequency of 1700 MHz. [33] The 400-watt transceiver uses a Quaternary Phase-Shift Keying (QPSK) modulation technique to encode the signal. Since the return link transmits large amounts of data, QPSK modulation is required to provide the maximum possible information flow for the bandwidth available. In fact, using a

QPSK modulation scheme will require half the bandwidth of a BPSK system give a specified data rate.[34]

4.1.3 The advantage of QPSK

This reduction in bandwidth is due to the fact that QPSK modulated signals are produced by two BPSK modulators operating together in quadrature. When the data transfer occurs the odd-numbered bits are sent to the *i* (in-phase) channel while the even-numbered bits are routed to the *q* (quadrature) channel.[35] The carrier signal is sent directly into the *i* channel but is phase shifted by 90 degrees before being fed into the *q* channel modulator. The *i* and *q* channel outputs are then combined to produce the final QPSK signal. Since the signal is comprised of two channels, the output state is dependent on a pair of bits. As illustrated in Figure 4.4, this results in 4 possible values that can be assumed by a QPSK symbol.[36] This is twice the number of states that can be produced by a standard BPSK modulation scheme.

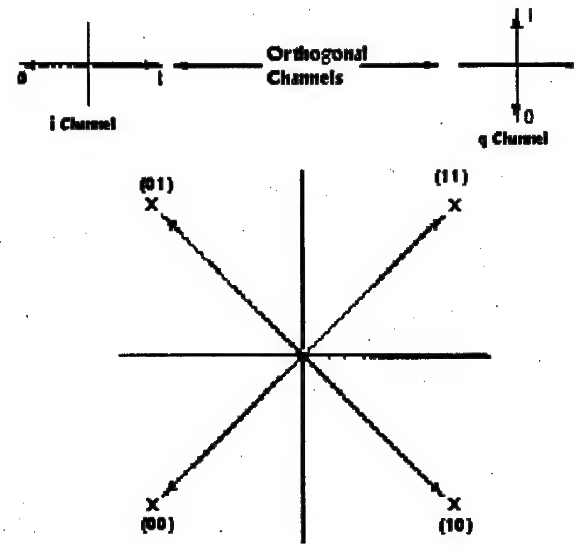

Figure 4.4 State Generation in QPSK

4.1.3 Link Analysis

Although an actual U-2 mission would more likely use a FLEET SATCOM or Milstar satellite to supply a data link, using a TDRS satellite for a link analysis provides an opportunity for numerical comparisons and significant insight on the data transfer

process. Using public available documentation of the STARLink system included in Appendix B, an elementary link analysis is possible. The link budget between the ER-2 and TDRS satellite was performed and is depicted in Appendix A. The evaluated result of ER-2 to TDRS link analysis is juxtaposed with documented results in Table 4.1.

Documented Margin 1	1.1 dB
Documented Margin 2	3.8 dB
Documented Margin 3	1.4 dB
Average of Documented Margins	2.1 dB
Original Evaluated Margin	5.3 dB
Difference	3.2 dB

Table 4.1 Original Link Analysis Results

Obviously there is a significant amount of discrepancy in the figures. A source of this difference was traced to a large difference in the transmitter power used to calculate the link budget. Reliable reference data acknowledged that STARLink employed a 400-watt uplink transmitter. [37] However, the link budget documented in Appendix B utilizes a transmitter power of 24.7 dBW or 295.12 watts. As shown in Table 4.2, when a link

Average of Documented Margins	2.1 dB
Evaluated Margin Using 295 watt Transmitter	4.0 dB
Absolute Difference	1.9 dB
Percent Difference	1.81%

Table 4.2 Link Analysis Results Using a 295-Watt Transmitter

analysis using the 295-watt transmitter power was performed a more comparable link margin result of 4.0 dBW was achieved. Although this value is more analogous to the documented link budgets, the original evaluated result is more practical. This is because of two main reasons. First of all the original evaluation uses the 400-watt transmitter value that is clearly documented. In addition, it also is a much more plausible link margin result. A link margin of 5.3 dB is fairly low. However, an average margin of 2.1 dB is dangerously low. Such a value would lead to questionable system performance under adverse conditions. Under the demands of a military U-2 mission, the uplink needs to be reliable and able to provide warfighters with the information they need despite adverse conditions.

For the TDRS downlink, the STARLink system utilizes an 18-meter parabolic dish based at White Sands, New Mexico. Obviously, in a combat situation, 18-meter dishes do not provide adequate mobility to provide ground stations near the battlefield. Therefore, a personal investigation was undertaken to determine what the most practical antenna size was to provide the link from a TDRS satellite to battle managers on the ground. The results are illustrated in Table 4.3. As can be seen an antenna size practical

Receiver Antenna Size	Downlink Margin
18 meter	12.03 dB
1 meter	-13.1 dB
3 meter	-3.5 dB
5 meter	.9 dB
7 meter	3.8 dB

Table 4.3 Downlink Margins for Various Receive Antenna Sizes

for a large aircraft (1-meter) can not supply the gain needed for a communications link. Thus, in the scenario, the data could not be directly transmitted to an E-3 AWACS. Instead the data could be downlinked to a ground based 7-meter antenna stationed near the battlefield. This size, although still large, could be integrated into a mobile ground station and provides a link margin comparable to the uplink.

4.2 Data Fusion

Data Fusion (DF) is a process of managing data and information, obtained from a diverse number of sources, that may be needed at anytime by operators and commanders. Keeping in character with RTIC systems, DF must be an adaptive process that can continuously convert data into a richer information through constant refinement and relay it for distribution at a moment's notice. [38] Data fusion is key to preventing the warfighter from being overloaded with too much information. As can be seen in Figure 4.5, performance is optimized under moderate workload conditions. However, as soon

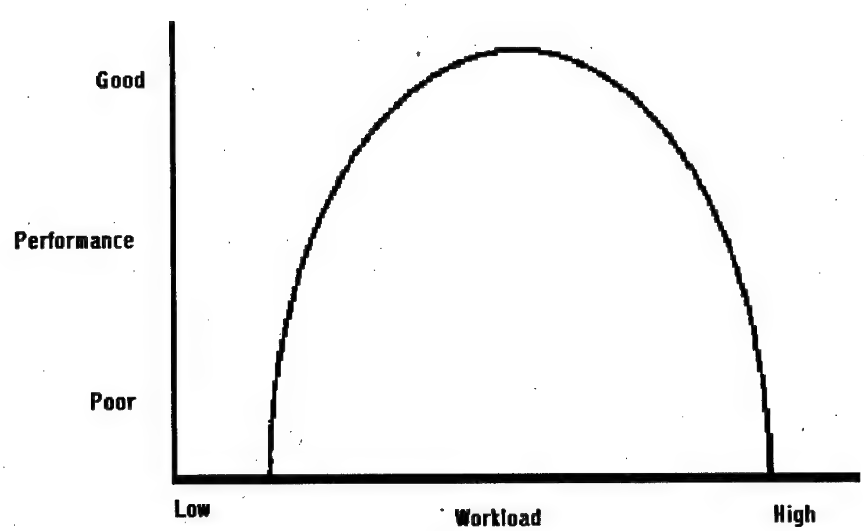

Figure 4.5 Performance versus Workload

as the workload increases beyond the moderate region, performance quickly drops. Thus, too much information can yield a situation often worse then no information at all.

Another facet of data fusion is ensuring the information is sorted in such a way that the warfighter receives the proper information at the proper time. For instance, the requested view of the target area may shift as the aircraft moves from 50 miles out to 5 miles out. The data fusion process must take into account pilot requests and the mission plan to ensure information will not be "pushed" to the warfighter.

To accomplish these tasks in real time a leap in data fusion technology must occur. [39] Currently we are able to collect data from a wide array of sensor platforms. However, as mentioned before, these data streams are processed independently in a stovepipe manner. Desert Storm illustrated the limitations in sharing and relating intelligence sources that is inherent to this processing architecture. Only limited views were supplied to the users instead of the whole picture required for effective combat operations.[40]

Reflecting back on the U-2 scenario presented earlier can provide some insight on the data fusion process in a present day context. Once the U-2 imagery is collected and relayed to the battle managers via a TDRS satellite, DF would step into play. The target image would be sent to a mobile command platform such as an AWACS or JOINT Stars aircraft. There, regional battle managers could select the image that would be most useful to the pilots and fuse other information together with the picture. For instance, instructional text could be superimposed on the image and the current threat situation including SAM position and any enemy aircraft in the area could be forwarded with the picture in one information package. The information in this intelligence package will be

dependent on the pilot's position in the mission and will contain only information that is pertinent at the time.

4.3 Data Dissemination

Once the collected data is fused, the ability to distribute it on demand and in real time becomes paramount. The information must be able to reach warfighters on mobile combat platforms under any conditions. However, the dissemination process not only includes transporting the requested information to the aircraft, but also ensuring it is presented in manner in which it can be rapidly assimilated by the receiving cockpit. As discussed earlier, information can easily overload the pilot and degrade mission performance. In a stressful combat situation, information that is not presented in simple and concise manner can cause more confusion than assistance.

4.3.1 Link-16

Once information is processed by a battle management center, it needs to be effectively and reliably transmitted to the mobile strike platform. The Armed Forces new tactical digital information link (TADIL) with the NATO designation "Link-16" is designed to accomplish this task. Link-16 does diverge from the basic information exchange concepts employed by previous data links such as Link-11 and Link-4A. Instead, Link-16 employs the Joint Tactical Information Distribution System (JTIDS) to provide significant technical and operational improvements to current tactical data link capabilities. [41] In the scenario, Link-16 would be the data link used to transmit the SCUD imagery fused with other information to the F-16 pilots on patrol.

The Link-16 system utilizes a Time Division Multiple Access (TDMA) scheme to provide multiple and apparently concurrent communication nets.[42] Each second of network time is divided into 128 "time slots" that are grouped into "sets" containing 512 time slots. The sets are interwoven together to minimize the chance of the information being compromised. A 12-second "frame" consists of three sets and along with the time slot is a basic unit of time used in the JTDIS network.[43]

In order to structure the functionality of Link-16, all JTIDS units are assigned time slots in which they transmit and receive data.[44] These time slots are parceled out

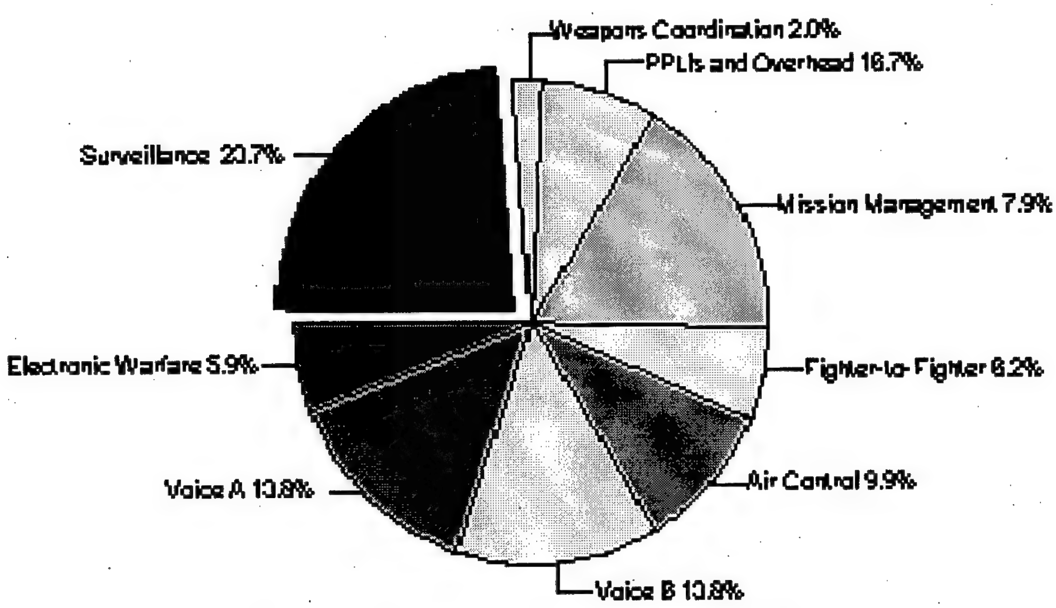

Figure 4.6 Network Partitions to NPGs

into Network Participation Groups (NPGs) according to the particular function the unit performs. Thus, through the time slot assignment, JTIDS units only participate on the NPGs used for the functions they perform.[45] For instance, certain NPGs are utilized for friendly force identification, position, and status information known as Precise Participant Location and Identification (PPLI) messages. Other NPGs include air control, battle

group surveillance, voice channels and other various battlefield tasks. Figure 4.6 illustrates how a typical Link-16 network's capabilities are partitioned to various NPGs.

Another improved feature of Link-16 is the ability to "stack" different NPGs on the same time slot. This is possible because of a technique known as frequency hopping. [46] The signal frequency in a time slot does not remain constant but instead randomly changes every 13 microseconds to one of 51 frequencies are available for JTIDS transmissions. This "hopping" is dictated by one of 128 hopping patterns that can be assigned to users. Thus, as illustrated in Figure 4.7, the same set of time slots may be

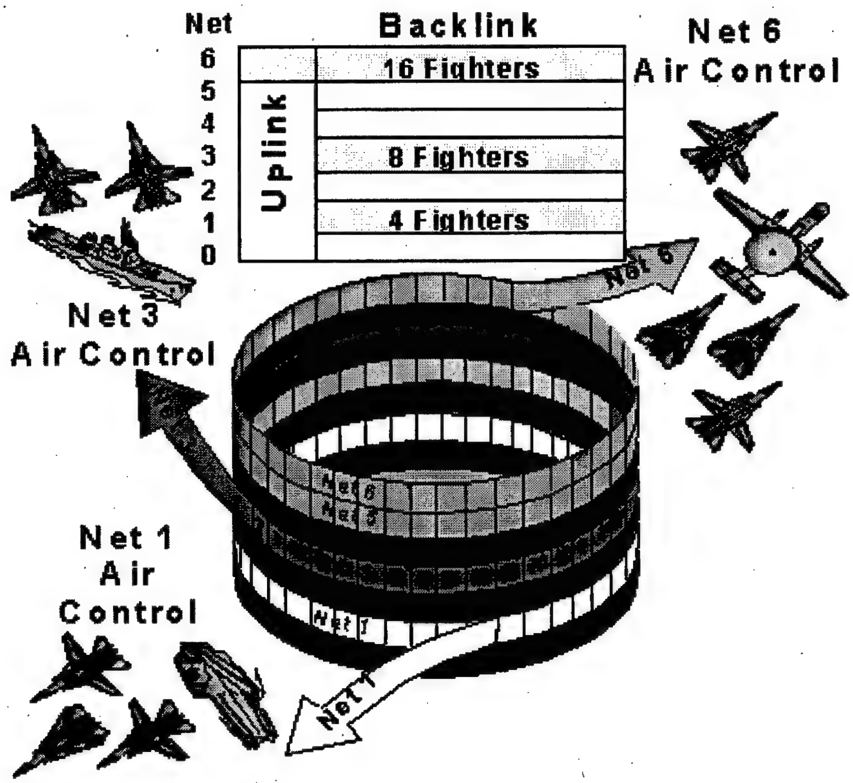

Figure 4.7 Stacking Nets

used for multiple users by simply assigning a different frequency hopping pattern to each. This stacking of NPGs is particularly useful for air control purposes by establishing exclusive sets of controlling units and regulated aircraft. [47] In addition, multiple voice

circuits are also possible by stacking NPGs. For instance, 127 voice channels are available on a single voice NPG.

It is noteworthy to illustrate some of the features unique to Link-16 that provides

	LINK-16	LINK-11	LINK-4A	LINK-4C
Surveillance/WC	YES	YES	NO	NO
Air Control	YES	NO	YES	NO
Fighter-to-Fighter	YES	NO	NO	YES
Secure Data	YES	YES	NO	NO
Extended LOS	YES (Relay)	YES (HF)	NO	NO
Secure Voice	YES (2 Channels)	NO	NO	NO
Jam Resistant	YES	NO	NO	NO
Positive ID	YES	LIMITED	LIMITED	LIMITED
Navigation	YES	NO	NO	NO
Data Forwarding	YES	NO	NO	NO
Flexible Net	YES	NO	NO	NO

Table 4.4 Link-16 Capabilities versus Other Data Links

this superiority. Table 4.4 showcases some of these Link-16 capabilities in comparison to existing communications data links. These and other capabilities that can not be discussed provide Link-16 with an unparalleled capability to transmit needed information to the aerial warfighter in real time. It is because of these reasons that without question, Link-16 is the tactical data link of choice for the Department of Defense and will be the means by which aerial warfighters are supplied with combat information in real time.

4.3.2 Information Displays

Although the intrinsic details of a single modern display system could easily warrant an investigation well beyond the scope of this paper, it is still noteworthy to

discuss some basic concepts of the systems that supply the information to aerial warfighters. In particular, head down displays, heads up displays and helmet mounted displays are the primary means real time information is presented to a pilot in the cockpit.

4.3.2.1 Head Down Displays

Originating with airborne radar scopes in World War II, Head Down Displays (HDDs) are the oldest form of electronic displays. HDDs provide the avenue by which the majority of cockpit information is presented. HDDs are used to supply navigation data, moving map displays, aircraft system status and numerous other types of information that is needed by a pilot. In addition, HDDs can provide imagery data from FLIR sensors, TV cameras and other imagery sources in their typical 5 x 5 inch size. In the SCUD scenario presented earlier, it would be an F-16 multi-function display that would display the target imagery and instructional text.[48]

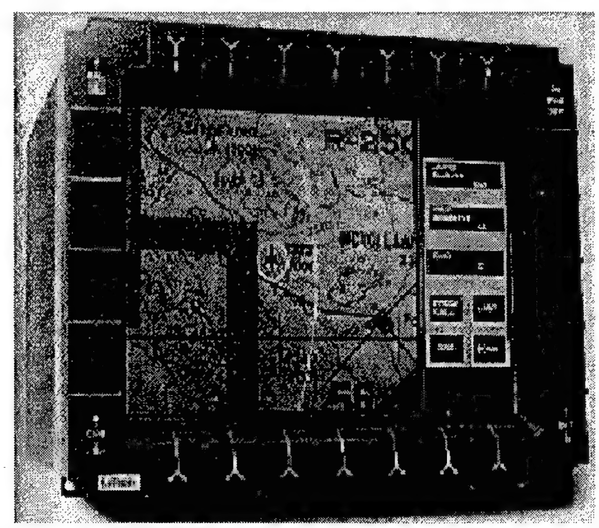

Figure 4.8 Modern Liquid Crystal HDD

HDDs are typically comprised of a cathode ray tube and controlling circuitry to adjust the presentation properties of the system. Due to visibility requirements in direct sunlight, these displays have traditionally been in a monochrome format. Specifically, the green CRT, which elicits the peak human visual response, became commonplace in fighter aircraft worldwide.[49] However, improvements in technology have enabled military cockpits to outfitted with color CRTs that are essential for video map displays.

Although CRTs are still the most common HDD technology, color liquid crystal displays (LCDs) and flat paneled displays will soon change the standard HDD found in a military cockpit. These types of displays can produce the resolution of a CRT without the space requirements of a cathode ray tube. Even though LCDs are not completely flat, they still only occupy a depth of two to three inches.[50] These systems will become standard in the next generation of fighter aircraft. Thus, even with the continued developments of heads up displays and helmet mounted sights, the HDD will still remain a necessary part of the RTIC system.

4.3.2.2 The Heads Up Display

When the United Kingdom's Buccaneer strike aircraft was introduced in 1962 it ushered in the most important advance in the visual presentation of data to the aviator thus far – the Heads Up Display (HUD).[51] Today the HUD is the primary means by which information is presented to the pilot. The continual development of the HUD has resulted in vast improvements to be made in man-machine interaction (MMI) by enabling the pilot to assimilate flight data while maintaining full visual contact with the outside world. This task is accomplished by the basic configuration illustrated in figure 4.9. The display symbology is generated by a cathode ray tube (CRT) and passes through a number of relay lenses that magnify the image and correct for inherent optical errors. The image is then reflected through a 90-degree angle by a fold mirror and proceeds to pass through a collimating lens. The collimating lens adjusts the image so that it will appear to the pilot as focused at infinity. This rather elementary concept is depicted in Figure 4.10. The collimating of the image allows the display to overlay the outside world

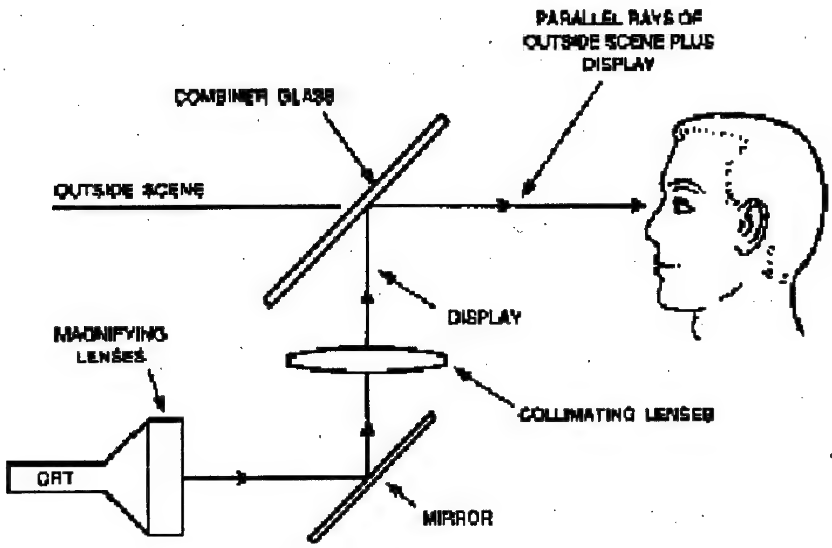

Figure 4.9 Heads Up Display Concept

and does not require the pilot to refocus his eyes or change the direction of his gaze. This capacity is crucial since the transition time to refocus the eyes from viewing distant to near objects requires one second or more. In addition, collimating also eliminates any parallax errors that might be encountered. Thus, the relation of the display symbols with

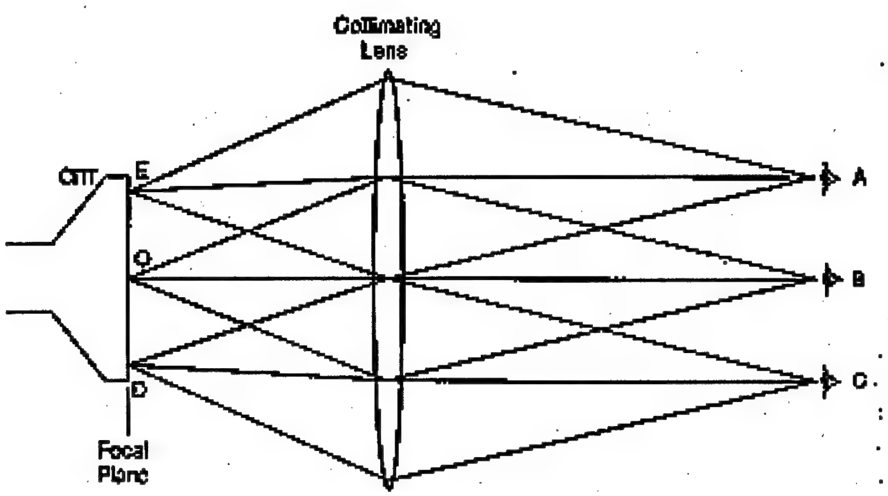

Figure 4.10 Line of Sight Trace of a Collimating Lens

the outside world remains unchanged with variations in the pilot's head movement.

The position of the collimating lens also determines a very important HUD parameter – the field of view (FOV). It is important to discern a HUD's instantaneous

field of view (IFOV) from the total field of view (TFOV). The two are not the same when considering a conventional heads up display. The IFOV is the angular coverage visible to the observer at any specific viewing point in the cockpit. It is a dependent on the diameter of the collimating lens, D, and the distance of the pilot's eyes from the collimating lens, L. The IFOV value may be determined by Equation (1). The total field

$$IFOV = 2\tan^{-1}\frac{D}{2L} \tag{1}$$

of view on the other hand is defined as the total angular coverage available to the observer by altering eye position. Unlike the IFOV, the TFOV is a function of the diameter of the display A, and the effective focal length, F, of the collimating lens. Equation (2) may be used to evaluate its value.[52] Looking at Equation (1), it is obvious

$$TFOV = 2\tan^{-1}\frac{A}{2F} \tag{2}$$

that the IFOV could be increased by simply bringing the pilot's eye position closer to the collimating lens. (Reducing L). However, because of cockpit geometry constraints, this is not a practical with the use of a conventional HUD.

Once the image passes through the collimating lenses it is projected onto the combiner glass. The combiner glass is basically a "see through" mirror that optically merges the outside world with the collimated display. The glass has high degree of optical transmission efficiency that minimizes the loss of visibility due to looking through the glass and windscreen. In modern designs the combiner glass can also be designed to contain curvature that enables the collimating to occur in the glass itself. As a result L is significantly decreased and the effective size of the collimating lens (D) can be increased.

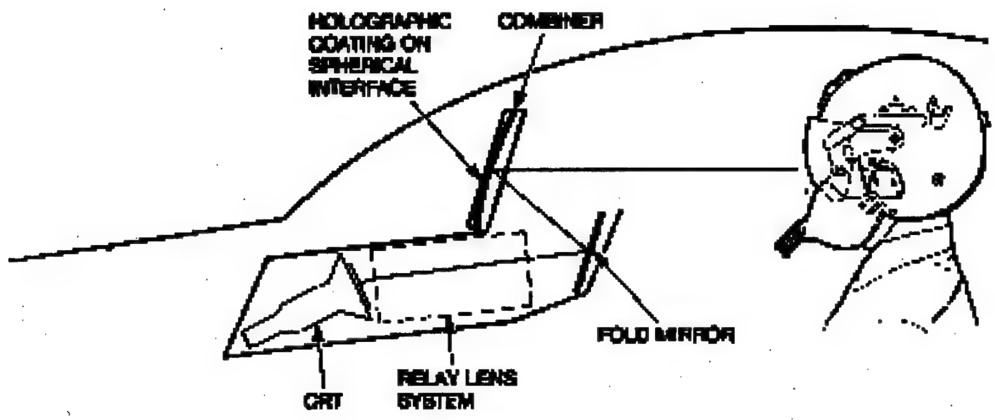

Figure 4.11 Holographic HUD Configuration

This heads up display design, known as a holographic HUD, can increase the IFOV by a factor of two or more. A holographic HUD is illustrated in Figure 4.11, note the absence of a separate collimating lens. This advancement renders the TFOV and IFOV in a holographic HUD to be roughly the same.[53] A wide FOV such as that supplied by a holographic HUD is particularly important when forward looking infrared (FLIR) information is displayed in the context of a night mission. In this case, the only visual information the pilot has of the outside world is the FLIR image displayed on the HUD.

4.3.2.3 The Helmet Mounted Display

Although the HUD has revolutionized the way flight information is presented to aviators, it has one distinct limitation – the information is only available in the pilot's forward field of view. Even with an advanced holographic HUD, the FOV is limited to 30 degrees in azimuth and 25 degrees in elevation.[54] To produce the most efficient sensor-to-shooter system, the pilot requires heads up visual information in all directions. This requirement can only be met with a helmet-mounted display (HMD).

A helmet mounted display in the simplest form is merely a basic target sighting system mounted on a flight helmet. These systems have been around for years and can provide some simple alphanumeric information to the user. However, in an advanced system, a HMD can in effect be a 'HUD on a helmet'. This concept can supply all information normally displayed on a HUD to the pilot looking in any direction. FLIR images and night vision goggles can also be incorporated into the system. In addition, since the effective collimating lens may be only a few inches from the pilot's eye, the FOV may be increased to nearly 40 degrees in a fighter aircraft. [55]

Figure 4.12 Modern HMD System

These potential advancements have spurred the United States to aggressively research the HMD concept. HMDs are unique in that they not only display information to the pilot but also provide a feedback loop to the information control system. A HMD system can estimate the pilot's line-of-sight and discern what external features are of importance. In short the HMD tells what the pilot is looking at so the system can provide information pertaining to the object of interest. In addition, the directional information of a pilot's gaze can also be linked to on board weapons sensors to aid in targeting. For instance, a typical air-to-air missile seeker needs to be directed to within 2 degrees of a target to achieve a missile lock. With the limited FOV of a HUD, this limits off-boresight attacks to a mere 15 degrees at best. However, with a helmet mounted targeting system, a highly agile missile can attack a target that is 120 degrees off of the nose of the aircraft. When

integrated into modern fighter aircraft, this improvement increases the air-to-air kill probability a factor of 3 or more. [56]

Although the United States Army has utilized HMD systems in their Apache helicopter for quite some time, difficulties have been encountered in employing the systems in high performance fighter aircraft. Specifically, size and weight constraints have been limiting factors. A conventional aircrew helmet normally weighs about 2.2 lbs. Yet, under the force of a 9g turn the helmet has an effective weight of 20 lbs. Currently HMD systems have a weight ranging from 3.8 to 5.5 lbs. This can yield up to 50 lbs of force bearing down on a pilot's head during a tight combat turn.[57] A force of this magnitude would be unbearable in a dogfight. Therefore, for HMDs to become practical in a fighter aircraft, advancements technology must be made that enable the system mass to be reduced to that of a conventional helmet.

In addition to size constraints, the aiming accuracy of a HMD has made it difficult to incorporate in fighter aircraft. The boresight error of a HMD can range from 5 to 10 or more milliradians. This is considerably larger than the 1-milliradian error of a typical heads up display. These errors directly impact the accuracy of weapons and their effectiveness. Thus, once technology enables the production of light weight HMDs, systems that combine HMDs and HUDs could become commonplace in fighter aircraft. This "best of both worlds" system would combine the unrestrained FOV of a HMD with the targeting accuracy of a HUD.

5. Conclusion

Several issues regarding the transfer of Real time Information into the cockpit were discussed over the course of this brief investigation. The concept of RTIC was explored revealing the definition, vision, characteristics and a typical design trade. It was concluded that an effective RTIC system must enable pilots to fashion their own information environment. The necessary supporting information grid was also investigated. The grid's capabilities, requirements and current limitations were presented. It was resolved that the grid must be flexible, secure, and reliable to adequately serve the warfighters of the future. Finally, the actual RTIC process of data collection, fusion, and dissemination was discussed and showcased in a U-2 to F-16 sensor-to-shooter scenario. The means of transporting the imagery data via STARLink to a forward ground station was described. The method of using Link 16 and a heads down display to present the information to the pilot was also explained.

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Appendix A

Link Budget Calculations

Link Budget Calculation Procedure

The following method was employed to calculate the link budget for the communications link from the ER-2 aircraft to the TDRS satellite. This same method was used to evaluate the link from the TDRS satellite to the ground station.

Step 1

The first step was to establish the carrier frequency that would be used in the communications link. The ER-2 uplink utilized a frequency of 15003.4 MHz.

Step 2

Next the satellite transmitter power, antenna size and antenna efficiency were established

Step 3

Losses between the transmitter and antenna were then estimated. An assumed value of 2.2 dB was used.

Step 4

Using equations (A-1) and (A-2) the carrier wavelength and antenna beamwidth were found.

$$\lambda = \frac{c}{f} \qquad \text{(A-1)}$$

$$\theta = \frac{21}{f_{Ghz} D} \qquad \text{(A-2)}$$

Step 5

The maximum antenna pointing offset angle was established based on the greatest amount error inherent in the STARLink system.

Step 6

The ER-2 transmit antenna gain was calculated using equation (A-3) The reduction from peak gain was also found using (A-4). These results were summed to yield a total transmit antenna gain.

$$G = -159.59 + 20LogD + 20Logf - 20\log c \quad \text{(A - 3)}$$

$$L_\theta = -12(\frac{e}{\theta})^2 \quad \text{(A - 4)}$$

Step 7

Finding the space loss was the next task. Before this could be accomplished the angular radius of the earth, the nadir angle, the earth central angle and slant range were found using equations (A-5), (A-6), (A-7), and (A-8) respectively. Then using (A-9) the free space loss was determined.

$$r_0 = A\sin(\frac{R_E}{R_E H}) \quad \text{(A - 5)}$$

$$\eta = A\sin(\cos\varepsilon\sin r_0) \quad \text{(A - 6)}$$

$$\lambda = 90 - \eta - \varepsilon \quad \text{(A - 7)}$$

$$D = R_E(\frac{\sin\lambda}{\sin\eta}) \quad \text{(A - 8)}$$

$$L_s = (\frac{c}{4\pi Df})^2 \quad \text{(A - 9)}$$

Step 8

Next the losses due to polarization mismatch and absorption of the atmosphere and radome were estimated. .3 dB was used for the polarization mismatch and 1 dB was

assumed to be absorbed by the radome. The atmospheric absorption was found by dividing the determined zenith attenuation by the sine of the minimum elevation angle.

Step 9

The receive antenna parameters were then specified. Equation (A-2) was again used to find beamwidth and the pointing error was estimated to be 10% of this value.

Step 10

The receive antenna gain is determined using (A-3) and (A-4)

Step 11

The system noise temperature is estimated using a reference table. Clear weather is assumed.

Step 12

Eb/No is found using equation (A-10) for the required data rate of 295 Mbits/sec.

$$\frac{E_b}{N_O} = \frac{PL_l G_t L_s L_a G_r}{kT_s R} \qquad \text{(A-10)}$$

Step 13

The required Eb/No to achieve a bit error rate of 10-8 using QPSK is stated. 10-8 is the bit error rate employed by STARLink

Step 14

1 dB is added to this theoretical value for a more practical number

Step 15

The difference of the calculated Eb/No and the required Eb/No is taken to yield the link margin.

Link budget from a ER-2 aircraft to a TDRS satellite

1. Select carrier frequency
Frequency
1.50E+10 Hz

2. ER-2 transmitter power

Transmit power in Watts	Efficency	Transmit Ant diameter (meter)
400	0.55	0.762

3. Rf losses between the transmitter and ER-2 antenna
-2.2 dB

4. Determine wavelength and beamwidth of ER-2 antenna
wavelength Eqn 1
0.019982 meters

Transmit ant beamwidth Eqn 2
(deg)
1.836854

5. Max antenna pointing offset angle
Pointing error (deg)
0.56 Amount of pointing error allowed

6. Calculate transmit antenna gain towards satellite
using equations 13-18 and 13-19

Transmit antenna gain

Gain=	38.97652 dB	Eqn 3
Losses=	-1.115342 dB	Eqn 4

Transmit antenna gain
37.86118 dB

7. Calculate space loss using equation 13-21

Find the max distance from ELT to microsat
Satellite separation = 35786 km

Min elevation angle (deg)
1.5 Given in specifications

ro=	0.151849 rad	Eqn 5
n=	0.151797 rad	Eqn 6

lambda= 79.80268 deg Eqn 7

D= 41512.2 km Eqn 8

Path length in meters
41512198

Space loss in dB Eqn 9
-208.3373

8. Estimate propagation absorption loss due to the atmosphere, Polarization mismatch and radome
Theoretical one way zenith attenuation
0.02 dB

Divide by sine of min elev angle
0.764031

Add 1 dB for radome and .3 dB for polarization mismatch
2.064031

9. Select the TDRS antenna diameter and estimate pointing error.
let the pointing error be 10% of the beamwidth. Use eqn 13-17 to calculate antenna beamwidth

Receive antenna diameter
4.9 m

Calculate the receive antenna beamwidth Eqn 2
1.948052
Pointing error = 10% of beamwidth (degrees)
0.194805

10. Calculate the receive antenna gain toward the ELT. (dB)

55.86685 dB	Eqn 3	Efficency	0.65
-0.12 dB	Eqn 4		

Receive Antenna Gain
55.74685 dB

11. Estimate the system noise temperature (in clear weather)

31.1 dB-K

12. Calculate Eb/No for the required data rate using equation 13-12

data rate (bps)	2.95E+08	bps with Reed Solomon encoded data
P[dBW]=	26.0206	
Ll=	-2.2	
Gt=	37.86118	
Ls=	-208.3373	
La=	-2.064031	
Gr=	55.74685	
Ts (dB-K) =	31.1	

Eb/No= 19.83036 dB Eqn 10

13 Required Eb/No to achieve BER of10^-8, using QPSK

13.5 dB

14. Add 1 to the theoretical value for implementation losses

14.5 dB I added 1 dB

15. Calculate the link margin-the difference between the expected value of Eb/No calculated and the required Eb/No (including implementation loss)

5.330363 dB

Link budget from a ER-2 aircraft to a TDRS satellite Using a 295 watt Tr

1. Select carrier frequency
Frequency
1.50E+10 Hz

2. ER-2 transmitter power

Transmit power in Watts	**Efficency**	**Transmit Ant diameter (meter)**
295.12	0.55	0.762

3. Rf losses between the transmitter and ER-2 antenna
-2.2 dB

4. Determine wavelength and beamwidth of ER-2 antenna
wavelength Eqn 1
0.019982 meters

Transmit ant beamwidth Eqn 2
(deg)
1.836854

5. Max antenna pointing offset angle
Pointing error (deg)
0.56 Amount of pointing error allowed

6. Calculate transmit antenna gain towards satellite
using equations 13-18 and 13-19

Transmit antenna gain

Gain=	38.97652 dB	Eqn 3
Losses=	-1.115342 dB	Eqn 4

Transmit antenna gain
37.86118 dB

7. Calculate space loss using equation 13-21

Find the max distance from ELT to microsat
Satellite separation = 35786 km

Min elevation angle (deg)
1.5 Given in specifications

ro=	0.151849 rad	Eqn 5
n=	0.151797 rad	Eqn 6

lambda= 79.80268 deg Eqn 7

D= 41512.2 km Eqn 8

Path length in meters
41512198

Space loss in dB Eqn 9
-208.3373

8. Estimate propagation absorption loss due to the atmosphere, Polarization mismatch and radome
Theoretical one way zenith attenuation
0.02 dB

Divide by sine of min elev angle
0.764031

Add 1 dB for radome and .3 dB for polarization mismatch
2.064031

9. Select the TDRS antenna diameter and estimate pointing error.
let the pointing error be 10% of the beamwidth. Use eqn 13-17 to calculate antenna beamwidth

Receive antenna diameter
4.9 m

Calculate the receive antenna beamwidth Eqn 2
1.948052
Pointing error = 10% of beamwidth (degrees)
0.194805

10. Calculate the receive antenna gain toward the ELT. (dB)

55.86685 dB	Eqn 3	Efficency	0.65
-0.12 dB	Eqn 4		

Receive Antenna Gain
55.74685 dB

11. Estimate the system noise temperature (in clear weather)

31.1 dB-K

12. Calculate Eb/No for the required data rate using equation 13-12

data rate (bps)	2.95E+08	bps with Reed Solomon encoded data
P[dBW]=	24.69999	
Ll=	-2.2	
Gt=	37.86118	
Ls=	-208.3373	
La=	-2.064031	
Gr=	55.74685	
Ts (dB-K) =	31.1	

Eb/No= 18.50975 dB Eqn 10

13 Required Eb/No to achieve BER of10^-8, using QPSK

13.5 dB

14. Add 1 to the theoretical value for implementation losses

14.5 dB I added 1 dB

15. Calculate the link margin-the difference between the expected value of Eb/No calculated and the required Eb/No (including implementation loss)

4.00975 dB

Link budget from a TDRS satellite to a Ground Station with an 18 meter

1. Select carrier frequency
Frequency
1.25E+10 Hz

2. ER-2 transmitter power

Transmit power in Watts	Efficency	Transmit Ant diameter (meter)
6	0.55	2

3. Rf losses between the transmitter and ER-2 antenna
-1 dB

4. Determine wavelength and beamwidth of ER-2 antenna
wavelength Eqn 1
0.023984 meters

Transmit ant beamwidth (deg) Eqn 2
0.84

5. Max antenna pointing offset angle
Pointing error (deg)
0.1 Amount of pointing error allowed

6. Calculate transmit antenna gain towards satellite
using equations 13-18 and 13-19

Transmit antenna gain

Gain=	45.77243 dB	Eqn 3
Losses=	-0.170068 dB	Eqn 4

Transmit antenna gain
45.60236 dB

7. Calculate space loss using equation 13-21

Find the max distance from ELT to microsat
Satellite separation = 35786 km

Min elevation angle (deg)
1.5 Given in specifications

ro=	0.151849 rad	Eqn 5
n=	0.151797 rad	Eqn 6

lambda= 79.80268 deg Eqn 7

D= 41512.2 km Eqn 8

Path length in meters
41512198

Space loss in dB Eqn 9
-206.7517

8. Estimate propagation absorption loss due to the atmosphere, Polarization mismatch and radome
Theoretical one way zenith attenuation
0.02 dB

Divide by sine of min elev angle
0.764031

Add .3 dB for polarization mismatch
1.064031

9. Select the TDRS antenna diameter and estimate pointing error.
let the pointing error be 10% of the beamwidth. Use eqn 13-17 to calculate antenna beamwidth

Receive antenna diameter
18 m

Calculate the receive antenna beamwidth Eqn 2
0.530303
Pointing error = 10% of beamwidth (degrees)
0.05303

10. Calculate the receive antenna gain toward the ELT. (dB)

65.58278 dB	Eqn 3	Efficency	0.65
-0.12 dB	Eqn 4		

Receive Antenna Gain
65.46278 dB

11. Estimate the system noise temperature (in clear weather)

27.4 dB-K

12. Calculate Eb/No for the required data rate using equation 13-12

data rate (bps)	2.95E+08	bps with Reed Solomon encoded data
P[dBW]=	7.781513	
Ll=	-1	
Gt=	45.60236	
Ls=	-206.7517	
La=	-1.064031	
Gr=	65.46278	
Ts (dB-K) =	27.4	

Eb/No= 26.53399 dB Eqn 10

13 Required Eb/No to achieve BER of10^-8, using QPSK

13.5 dB

14. Add 1 to the theoretical value for implementation losses

14.5 dB I added 1 dB

15. Calculate the link margin-the difference between the expected value of Eb/No calculated and the required Eb/No (including implementation loss)

12.03399 dB

Link budget from a TDRS satellite to a Ground Station, 3 meter dish

1. Select carrier frequency
Frequency
1.25E+10 Hz

2. ER-2 transmitter power

Transmit power in Watts	**Efficency**	**Transmit Ant diameter (meter)**
6	0.55	2

3. Rf losses between the transmitter and ER-2 antenna
-1 dB

4. Determine wavelength and beamwidth of ER-2 antenna
wavelength Eqn 1
0.023984 meters

Transmit ant beamwidth Eqn 2
(deg)
0.84

5. Max antenna pointing offset angle
Pointing error (deg)
0.1 Amount of pointing error allowed

6. Calculate transmit antenna gain towards satellite
using equations 13-18 and 13-19

Transmit antenna gain

Gain=	45.77243 dB	Eqn 3
Losses=	-0.170068 dB	Eqn 4

Transmit antenna gain
45.60236 dB

7. Calculate space loss using equation 13-21

Find the max distance from ELT to microsat
Satellite separation = 35786 km

Min elevation angle (deg)
1.5 Given in specifications

ro=	0.151849 rad	Eqn 5
n=	0.151797 rad	Eqn 6

lambda= 79.80268 deg Eqn 7

D= 41512.2 km Eqn 8

Path length in meters
41512198

Space loss in dB Eqn 9
-206.7517

8. Estimate propagation absorption loss due to the atmosphere, Polarization mismatch and radome
Theoretical one way zenith attenuation
0.02 dB

Divide by sine of min elev angle
0.764031

Add .3 dB for polarization mismatch
1.064031

9. Select the TDRS antenna diameter and estimate pointing error.
let the pointing error be 10% of the beamwidth. Use eqn 13-17 to calculate antenna beamwidth

Receive antenna diameter
3 m

Calculate the receive antenna beamwidth Eqn 2
3.181818
Pointing error = 10% of beamwidth (degrees)
0.318182

10. Calculate the receive antenna gain toward the ELT. (dB)

50.01976 dB	Eqn 3	Efficency	0.65
-0.12 dB	Eqn 4		

Receive Antenna Gain
49.89976 dB

11. Estimate the system noise temperature (in clear weather)

27.4 dB-K

12. Calculate Eb/No for the required data rate using equation 13-12

data rate (bps)	2.95E+08	bps with Reed Solomon encoded data
P[dBW]=	7.781513	
Ll=	-1	
Gt=	45.60236	
Ls=	-206.7517	
La=	-1.064031	
Gr=	49.89976	
Ts (dB-K) =	27.4	

Eb/No= 10.97096 dB Eqn 10

13 Required Eb/No to achieve BER of10^-8, using QPSK

13.5 dB

14. Add 1 to the theoretical value for implementation losses

14.5 dB I added 1 dB

15. Calculate the link margin-the difference between the expected value of Eb/No calculated and the required Eb/No (including implementation loss)

-3.52904 dB

Link budget from a TDRS satellite to a Ground Station, 5 meter dish

1. Select carrier frequency
Frequency
1.25E+10 Hz

2. ER-2 transmitter power

Transmit power in Watts	**Efficency**	**Transmit Ant diameter (meter)**
6	0.55	2

3. Rf losses between the transmitter and ER-2 antenna
-1 dB

4. Determine wavelength and beamwidth of ER-2 antenna
wavelength Eqn 1
0.023984 meters

Transmit ant beamwidth Eqn 2
(deg)
0.84

5. Max antenna pointing offset angle
Pointing error (deg)
0.1 Amount of pointing error allowed

6. Calculate transmit antenna gain towards satellite
using equations 13-18 and 13-19

Transmit antenna gain

Gain=	45.77243 dB	Eqn 3
Losses=	-0.170068 dB	Eqn 4

Transmit antenna gain
45.60236 dB

7. Calculate space loss using equation 13-21

Find the max distance from ELT to microsat
Satellite separation = 35786 km

Min elevation angle (deg)
1.5 Given in specifications

ro=	0.151849 rad	Eqn 5
n=	0.151797 rad	Eqn 6

lambda= 79.80268 deg Eqn 7

D= 41512.2 km Eqn 8

Path length in meters
41512198

Space loss in dB Eqn 9
-206.7517

8. Estimate propagation absorption loss due to the atmosphere, Polarization mismatch and radome
Theoretical one way zenith attenuation
0.02 dB

Divide by sine of min elev angle
0.764031

Add .3 dB for polarization mismatch
1.064031

9. Select the TDRS antenna diameter and estimate pointing error.
let the pointing error be 10% of the beamwidth. Use eqn 13-17 to calculate antenna beamwidth

Receive antenna diameter
5 m

Calculate the receive antenna beamwidth Eqn 2
1.909091
Pointing error = 10% of beamwidth (degrees)
0.190909

10. Calculate the receive antenna gain toward the ELT. (dB)

54.45673 dB	Eqn 3	Efficency	0.65
-0.12 dB	Eqn 4		

Receive Antenna Gain
54.33673 dB

11. Estimate the system noise temperature (in clear weather)

27.4 dB-K

12. Calculate Eb/No for the required data rate using equation 13-12

data rate (bps)	2.95E+08	bps with Reed Solomon encoded data
P[dBW]=	7.781513	
Ll=	-1	
Gt=	45.60236	
Ls=	-206.7517	
La=	-1.064031	
Gr=	54.33673	
Ts (dB-K) =	27.4	

Eb/No= 15.40794 dB Eqn 10

13 Required Eb/No to achieve BER of10^-8, using QPSK

13.5 dB

14. Add 1 to the theoretical value for implementation losses

14.5 dB I added 1 dB

15. Calculate the link margin-the difference between the expected value of Eb/No calculated and the required Eb/No (including implementation loss)

0.907935 dB

Link budget from a TDRS satellite to a Ground Station, 7 meter dish

1. Select carrier frequency
Frequency
1.25E+10 Hz

2. ER-2 transmitter power

Transmit power in Watts	**Efficency**	**Transmit Ant diameter (meter)**
6	0.55	2

3. Rf losses between the transmitter and ER-2 antenna
-1 dB

4. Determine wavelength and beamwidth of ER-2 antenna
wavelength Eqn 1
0.023984 meters

Transmit ant beamwidth Eqn 2
(deg)
0.84

5. Max antenna pointing offset angle
Pointing error (deg)
0.1 Amount of pointing error allowed

6. Calculate transmit antenna gain towards satellite
using equations 13-18 and 13-19

Transmit antenna gain

Gain=	45.77243 dB	Eqn 3
Losses=	-0.170068 dB	Eqn 4

Transmit antenna gain
45.60236 dB

7. Calculate space loss using equation 13-21

Find the max distance from ELT to microsat
Satellite separation = 35786 km

Min elevation angle (deg)
1.5 Given in specifications

ro=	0.151849 rad	Eqn 5
n=	0.151797 rad	Eqn 6

lambda= 79.80268 deg Eqn 7

D= 41512.2 km Eqn 8

Path length in meters
41512198

Space loss in dB Eqn 9
-206.7517

8. Estimate propagation absorption loss due to the atmosphere, Polarization mismatch and radome
Theoretical one way zenith attenuation
0.02 dB

Divide by sine of min elev angle
0.764031

Add .3 dB for polarization mismatch
1.064031

9. Select the TDRS antenna diameter and estimate pointing error.
let the pointing error be 10% of the beamwidth. Use eqn 13-17 to calculate antenna beamwidth

Receive antenna diameter
7 m

Calculate the receive antenna beamwidth Eqn 2
1.363636
Pointing error = 10% of beamwidth (degrees)
0.136364

10. Calculate the receive antenna gain toward the ELT. (dB)

57.37929 dB	Eqn 3	Efficency	0.65
-0.12 dB	Eqn 4		

Receive Antenna Gain
57.25929 dB

11. Estimate the system noise temperature (in clear weather)

27.4 dB-K

12. Calculate Eb/No for the required data rate using equation 13-12

data rate (bps)	2.95E+08	bps with Reed Solomon encoded data
P[dBW]=	7.781513	
Ll=	-1	
Gt=	45.60236	
Ls=	-206.7517	
La=	-1.064031	
Gr=	57.25929	
Ts (dB-K) =	27.4	

Eb/No= 18.3305 dB Eqn 10

13 Required Eb/No to achieve BER of10^-8, using QPSK

13.5 dB

14. Add 1 to the theoretical value for implementation losses

14.5 dB I added 1 dB

15. Calculate the link margin-the difference between the expected value of Eb/No calculated and the required Eb/No (including implementation loss)

3.830496 dB

Link budget from a TDRS satellite to a Ground Station, 1 meter dish

1. Select carrier frequency
Frequency
1.25E+10 Hz

2. ER-2 transmitter power

Transmit power in Watts	**Efficency**	**Transmit Ant diameter (meter)**
6	0.55	2

3. Rf losses between the transmitter and ER-2 antenna
-1 dB

4. Determine wavelength and beamwidth of ER-2 antenna
wavelength Eqn 1
0.023984 meters

Transmit ant beamwidth (deg) Eqn 2
0.84

5. Max antenna pointing offset angle
Pointing error (deg)
0.1 Amount of pointing error allowed

6. Calculate transmit antenna gain towards satellite
using equations 13-18 and 13-19

Transmit antenna gain

Gain=	45.77243 dB	Eqn 3
Losses=	-0.170068 dB	Eqn 4

Transmit antenna gain
45.60236 dB

7. Calculate space loss using equation 13-21

Find the max distance from ELT to microsat
Satellite separation = 35786 km

Min elevation angle (deg)
1.5 Given in specifications

ro=	0.151849 rad	Eqn 5
n=	0.151797 rad	Eqn 6

lambda=	79.80268 deg	Eqn 7
D=	41512.2 km	Eqn 8

Path length in meters
41512198

Space loss in dB Eqn 9
-206.7517

8. Estimate propagation absorption loss due to the atmosphere, Polarization mismatch and radome
Theoretical one way zenith attenuation
0.02 dB

Divide by sine of min elev angle
0.764031

Add .3 dB for polarization mismatch
1.064031

9. Select the TDRS antenna diameter and estimate pointing error.
let the pointing error be 10% of the beamwidth. Use eqn 13-17 to calculate antenna beamwidth

Receive antenna diameter
1 m

Calculate the receive antenna beamwidth Eqn 2
9.545455
Pointing error = 10% of beamwidth (degrees)
0.954545

10. Calculate the receive antenna gain toward the ELT. (dB)

40.47733 dB	Eqn 3	Efficency	0.65
-0.12 dB	Eqn 4		

Receive Antenna Gain
40.35733 dB

11. Estimate the system noise temperature (in clear weather)

27.4 dB-K

12. Calculate Eb/No for the required data rate using equation 13-12

data rate (bps)	2.95E+08	bps with Reed Solomon encoded data
P[dBW]=	7.781513	
Ll=	-1	
Gt=	45.60236	
Ls=	-206.7517	
La=	-1.064031	
Gr=	40.35733	
Ts (dB-K) =	27.4	

Eb/No= 1.428535 dB Eqn 10

13 Required Eb/No to achieve BER of10^-8, using QPSK

13.5 dB

14. Add 1 to the theoretical value for implementation losses

14.5 dB I added 1 dB

15. Calculate the link margin-the difference between the expected value of Eb/No calculated and the required Eb/No (including implementation loss)

-13.07146 dB

Appendix B

Radio Frequency Interface Control Document between the STARLink Program and the Tracking and Data Relay Satellite System

531-RFICD-SP/TDRSS

MISSION OPERATIONS & DATA SYSTEMS DIRECTORATE

Radio Frequency Interface Control Document between the STARLink Program and the Tracking and Data Relay Satellite System

November 28, 1995

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and
Space Administration

Radio Frequency Interface Control Document between the STARLink Program and the Tracking and Data Relay Satellite System

November 28, 1995

Prepared Under
Contract NAS5-31260

Approval for the Mission Operations and Data Systems Directoratre:

12/4/95

Philip Liebrecht, Chief of Networks Division — Date

Frank Stocklin — 12/1/95

Frank Stocklin,
RF Interface and Mission Analysis Section Head — Date

Ronald Vento — 11/30/95

Ron Vento, Networks Systems Engineer — Date

Approval for the STARLink Program Office:

Andrew C. Roberts — 11/21/95

Andrew Roberts, STARLink Project Manager — Date

Goddard Space Flight Center
Greenbelt, Maryland

531-RFICD-SP/TDRSS

Preface

This document describes the means for establishing performance requirements and for defining and controlling technical aspects of the radio frequency system interface between STARLink and the Tracking and Data Relay Satellite System.

Comments or questions concerning this document should be addressed to

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771
Attention: Network Systems Engineer for STARLink, Code 531.1

This document is under the configuration management of the Mission Operations and Data Systems Directorate (MO&DSD) Configuration Control Board (CCB). Configuration change requests to this document shall be submitted to the MO&DSD CCB, along with supportive material that justifies the proposed change.

Change Information Page

List of Effective Pages	
Page Number	**Issue**

Document History			
Document Number	**Status/Issue**	**Publication Date**	**CCR Number**
531-RFICD-SP/ TDRSS	Original	November 1995	

DCN Control Sheet

DCN Number	Date/Time Group	Month/ Year	Section(s) Affected	Initials

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1. Introduction

1.1 Purpose

This interface control document (ICD) establishes performance requirements and defines and controls the technical aspects of the radio frequency (RF) system interface between the Satellite Telemetry and Return Link (STARLink) and the Tracking and Data Relay Satellite System (TDRSS). The interfaces defined herein are also applicable during compatibility tests with the STARLink antenna located at the integration facility's rooftop.

1.2 Interface Responsibilities

The interface responsibilities are defined in terms of the STARLink Program (SP) office and the Mission Operations & Data Systems Directorate (MO&DSD). The element identified as the STARLink flight segment, hereafter referred to as the Flight Vehicle Terminal (FVT), will be the responsibility of the STARLink Program Office. The element identified as TDRSS is the responsibility of the Networks Division at Goddard Space Flight Center (GSFC).

The design requirements and parameters in this ICD are subject to the bilateral control of the STARLink Program Office and the Networks Division. These offices will jointly approve the ICD and any subsequent changes thereto, following resolution of issues and discrepancies.

1.3 Interface Identification

The communication links defined and controlled by this ICD are the RF transmission between the STARLink and TDRSS, as defined in sections 3 and 4.

2. Documents

2.1 Applicable Documents

The *Detailed Mission Requirements (DMR) for STARLink, January 1995,* defines the top–level requirements for this ICD. In the event of conflict between this ICD and the DMR, the DMR takes precedence.

2.2 Reference Documents

The latest issues of the following documents are for reference only:

a. Networks Users Guides:

1. *Spaceflight Tracking and Data Network Users Guide (Basic)*, STDN No. 101.1

2. *Space Network (SN) Users Guide*, STDN No. 101.2, Rev. 7

b. *Guidelines for Preparation of the User/TDRSS Radio Frequency Interface Control Document*, STDN No. 102.6.

c. *Interface Control Document Between the STARLink Project and the Second TDRSS Ground Terminal (STGT),* Version 1.0, January 1995, 530–ICD–STGT/STARLink.

d. *STARLink Ground Subsystem Internal Interface Control Document*, 8100118

These documents are not part of this ICD and are not controlled by virtue of their reference herein. In the event of a discrepancy, this ICD takes precedence.

3. Interface Requirements

3.1 General

This section specifies the functional and performance requirements for both the Ku-band Single Access (KSA) forward (TDRSS-to-STARLink) and return (STARLink-to-TDRSS) links.

3.2 Interface Functional Requirements

3.2.1 General

The STARLink-TDRSS forward and return links will provide the functional capabilities described in the following sections when line of sight exists.

3.2.2 Commands

56 kbps data will originate at Ames Research Center (ARC) and will be transported to GSFC via National Aeronautics and Space Administration Communications (NASCOM) in the 4800 bit block format. White Sands Complex (WSC) will receive this data and extract the data and input it into the StarLink Unique Equipment (SLUE) at WSC. The User Payload Operations Control Center (POCC) will also provide the SLUE with voice-grade data. The SLUE will mux the 56 kbps bit stream, the voice-grade signal, and other SLUE generated data at WSC. The SLUE Link Controller (LC) will frame and format the composite forward link data stream and will perform differential encoding, rate 1/2 convolutional encoding, and interleaving as described in Section 4.3.2. The resulting signal will be a 400 kilosymbol/second signal in Non-Return to Zero-L (NRZ-L) format. WSC will Binary Phase Shift Key (BPSK) modulate this signal onto the Space-to-Ground Link (SGL) carrier. Pseudorandom Noise (PN) coding is not used. WSC relays this signal to STARLink via the Tracking and Data Relay Satellite (TDRS) using the KSA forward-link service with either Right Hand Circular Polarization (RHCP) or Left Hand Circular Polarization (LHCP). The STARLink will receive the 13.775 GHz carrier via a high gain KSA antenna. The signal is routed to a Low Noise Amplifier (LNA) and an autotrack receiver. The antenna autotrack receiver detects error signals which are used to control antenna pointing. The LNA signal is downconverted and passed to a BPSK demodulator, which demodulates the signal. The demodulator signal is then passed to a bit synchronizer. The baseband signal is demuxed into the command data and the digitized voice signal.

The STARLink airborne antenna is a 32 inch steerable (from -15° to 85° elevation and from 0° to 360° azimuth [no wrap]) and provides a 37.0 dB gain.

3.2.3 Science Data

The STARLink return data consists of multiple data streams with composite data rates less than 48 Mbps and digitized voice. One 21.42 Mbps data stream will be rate 1/2 encoded and interleaved. These streams and digitized voice will be multiplexed, bit stuffed, PN spread, and framed within the STARLink high data rate mux on the airborne terminal to make a 274.176 Mbps

bit stream. The 274.176 Mbps data consists of 137.088 Mbps on the I channel and 137.088 Mbps data on the Q channel. When RS coding is enabled, both channels are independently (254, 238) Reed Solomon (RS) coded to produce a 294.912 Mbps RS encoded bit stream with 147.456 Mbps on both channels. (Once the Reed Solomon encoder is installed in STARLink, all links are expected to be Reed Solomon encoded). Both I and Q channels are in NRZ-L format. The PN coding, rate 1/2 convolutional coding, Reed Solomon coding, interleaving, muxing, bit stuffing, and framing performed by STARLink is transparent to TDRSS. Both channels are Staggered Quadrature Phase Shift Key (SQPSK) modulated (with an I/Q power ratio of 1/1) onto a nominal 15003.4 MHz carrier. The return link carrier is noncoherent with the forward signal. The return link carrier will be derived within the STARLink to provide a fixed frequency with an accuracy of ±5 kHz. The return signal is amplified and radiated to TDRS using either LHCP or RHCP.

TDRS receives and relays the signal to WSC, where it is received, converted to baseband, and passed to the SLUE in NRZ-L format. A SLUE will process the signal and demux it into up to four baseband signals and the voice signal as described in Section 4.3.3. The SLUE converts the voice data into an analog signal and routes it and a 9.6 kbps SLUE status data stream to ARC via NASCOM 2000 equipment. Up to four science data bit streams are routed through the High Rate Black Switch (HRBS) to the input channels of the WSC Statistical Multiplexer (STATMUX). A single stream of up to 48 Mbps signal is output from the STATMUX and is transported to ARC via Domestic Satellite (DOMSAT).

The 32 inch steerable antenna provides a gain of 37.8 dB.

3.2.4 Doppler Tracking

Doppler tracking services are not required.

3.2.5 Ranging

Ranging services are not required.

3.3 Communications Performance Requirements

3.3.1 General

The STARLink-TDRSS forward and return links will meet the performance requirements described in the following sections when line of sight exists. TDRSS will commit to support whenever the look angle to TDRS is 1.5 degrees above the Earth tangential. TDRSS may acquire earlier and collect telemetry prior to the 1.5 degree criterion, but the data may contain dropouts due to atmospheric effects.

3.3.2 Command Channel

KSA forward-link service will not be available when the Sun's center is within 1 degree of the TDRS KSA or STARLink antenna boresights. Also, coordination with the appropriate RF regulatory organizations may be required to address flux density concerns arising from the absence of PN coding on the forward link.

3.3.3 Science Data Channel

The maximum information bit error rate and bit slippage rate (BSR) for the wideband digital data channel at the White Sands Complex (WSC) will be 10^{-5} and 10^{-12}, respectively. These capabilities are predicated on satisfactory compliance with the TDRSS-required communication systems performance parameters (user constraints) defined in Section 4.4.7, unless otherwise stated. Failure to meet these constraints results in degraded performance. Additional EIRP may be required to compensate for the degradation. KSA return-link service will not be available when the Sun's center is within 1 degree of the TDRS KSA or the WSC receiving antenna supporting that TDRS.

4. Link Interface Characteristics

4.1 General

4.2 Link Functional Design

4.2.1 General

The TDRSS-to-STARLink KSA forward link service will be provided on a scheduled basis concurrent with a STARLink-to-TDRSS KSA return link. The signal parameters for both links are shown in Table 4-1 and 4-2. The SN will support the STARLink, but it does not guarantee a 10^{-5} BER when the received power is less than the sum of the minimum Prec and the signal losses given in Table 4-2.

Open-loop pointing of the TDRS KSA antenna is intended as the primary tracking mode, with autotrack as a secondary option. In both cases, the required KSA antenna pointing vectors will be provided to minimize pointing loss.

4.2.2 Forward Link

The forward link functional design is shown in Figure 4-1 and is as follows:

a. Forward-link command and voice data will be received at WSC at a rate of 400 kbps in nonreturn to zero level (NRZ-L) format.

b. The forward-link signal will be BPSK modulated onto the SGL carrier and transmitted to the STARLink via TDRS. PN coding will not be used. The carrier frequency is doppler compensated although the capability exists to inhibit doppler compensation.

c. In the TDRS, the signal is coherently downconverted to the user receive frequency which is nominally 13.775 GHz and forwarded to the STARLink HGA with either RHCP or LHCP.

d. In the STARLink, the HGA receives the KSAF signal and routes it to the LNA, which passes it to the downconverter and autotrack receiver.

e. The downconverter downconverts the signal and passes it to the command receiver which will provide coherent Phase Shift-Key (PSK) demodulation of the suppressed carrier signal and deliver the command signal to the bit synchronizer for BPSK bit detection. A Viterbi decoder and deinterleaver reduce the 400 kbps forward link to 200 kpps. A demultiplexer separates the voice and command data signals.

f. The autotrack receiver detects the error signals, which are used to control antenna pointing.

Table 4–1 Forward-Link Signal Parameters

Data Rate	Data Format	Convol-utional Coding	PN Coding	Modu-lation	Carrier Frequency	Min TDRS EIRP	Antenna Polariz-ation
400 kbps	NRZ-L	None	None	BPSK	13.775 GHz nominal	40 dBW during autotrack acquisition and during TDRSS open loop pointing mode. 46.5 dBW after autotrack acquisition	LHCP or RHCP

Table 4–2 Return-Link Signal Parameters

Link	Chan-nel	Data Rate (Mbps)	Data Format	Convol-utional Coding	PN Coding	Modu-lation	Carrier Frequency	Antenna Polariz-ation	Required Effective Power (dBW) Per Channel	Other Losses
1	I	137.088	NRZ-L	None	None	SQPSK I/Q = 1/1	Mode DG2, Noncoherent, 15003.4 GHz	LHCP or RHCP	Autotrack enabled: -156.4 Autotrack disabled: -153.9	3.9 dB
	Q	137.088	NRZ-L	None	None					
2	I	147.456	NRZ-L	None	None	SQPSK I/Q = 1/1	Mode DG2, Noncoherent, 15003.4 GHz	LHCP or RHCP	Autotrack enabled: -156.1 Autotrack disabled: -153.6	3.9 dB
	Q	147.456	NRZ-L	None	None					

Note: 1. Required effective power (zero constraint loss, zero RFI loss, and zero polarization loss) required for 10^{-5} BER at the specified data rate and signal parameters.

2. Other losses include pointing loss, polarization loss, user-constraint loss, and RFI loss.

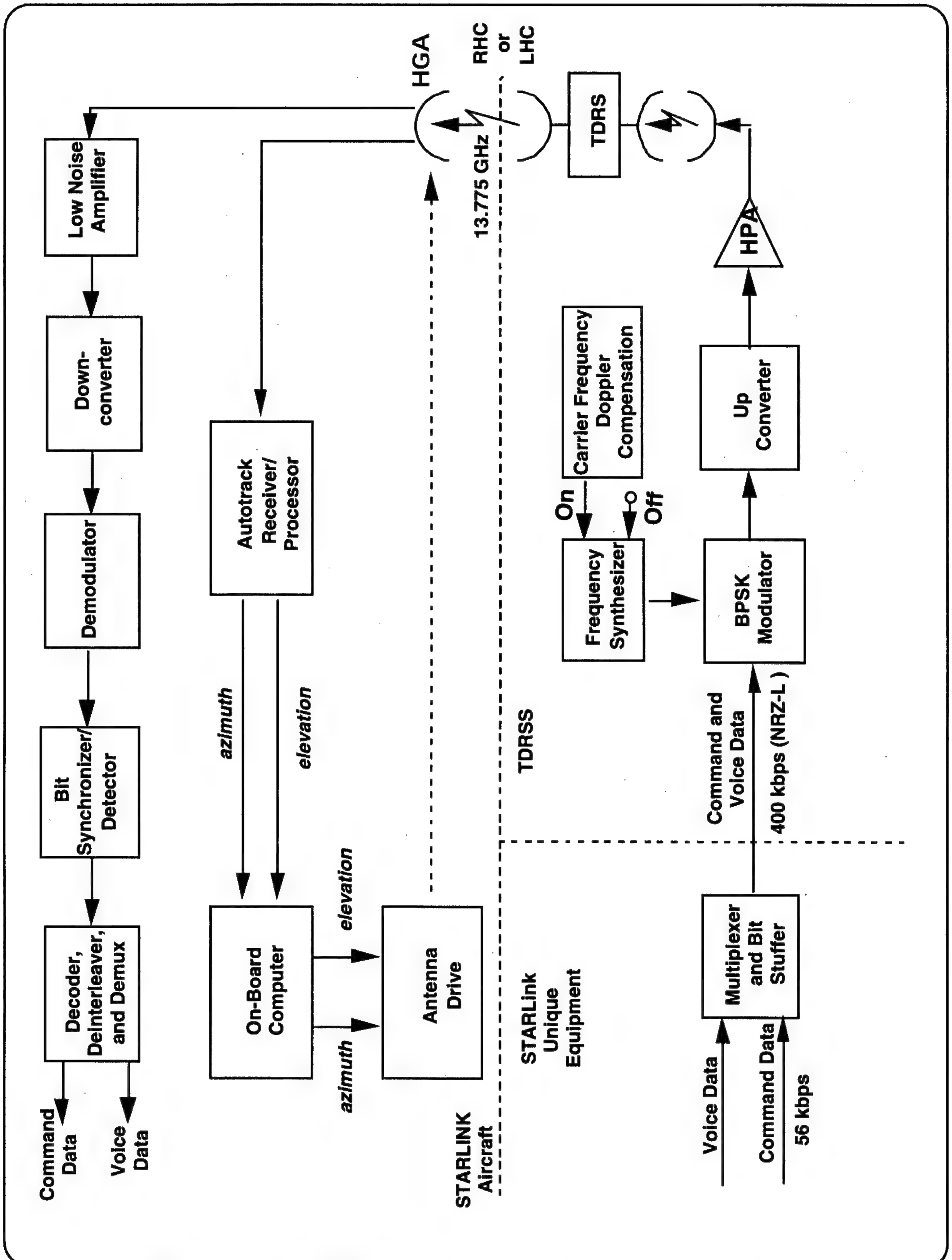


Figure 4-1 TDRSS-to-STARLINK KSA Forward Link

4.2.3 Return Link

The return link functional design is shown in Figure 4-2 and is as follows:

a. Reed Solomon encoded science data at 147.456 Mbps or uncoded data at 137.088 Mbps is transmitted on the I and Q channels. (Both channels have identical data rates). Any PN coding, interleaving, and rate 1/2 convolutional coding on the signal is transparent to TDRSS.

b. The return-link data format is NRZ-L.

c. Both channels are SQPSK modulated (with an I/Q power ratio of 1/1) onto a 15003.4 MHz carrier. The I/Q channel power division ratio will be 1:1 to within ± 0.4 dB. The phase of the I channel leads the phase of the Q channel by 90_. The data on the Q channel will be delayed one-half bit period with respect to the I channel.

d. The return link carrier is noncoherent with the forward signal. The return link carrier will be derived within the STARLink to provide a fixed frequency with an accuracy of ±5 kHz.

e. The return signal is amplified and radiated to TDRS using the KSA DG2 return service with either LHCP or RHCP.

f. TDRS receives and relays the signal to WSC.

g. WSC receives the signal, performs coherent SQPSK demodulation, and provides the I and Q channel signals in NRZ-L format to the SLUE, together with the recovered data clock.

h. The SLUE processes the signal (deinterleaving, decoding, despreading, extracting data from frame format), and demuxes the return signal as described in Section 4.3.3.

4.3 Baseband Signal Descriptions

4.3.1 General

This section describes the forward and return signal processing by the SLUE, which is transparent to TDRSS.

4.3.2 Forward-Link Baseband Signal Parameters

The SLUE LC will frame and format the composite forward link data stream, will then perform differential encoding, rate 1/2 convolutional encoding, and interleaving to transform the input signal to the WSC Low Rate Black Switch (LRBS) into the required 400 kbps NRZ-L differential Transistor-Transistor Logic (TTL) signal.

The interleaving depth is 1024 bits. The differential encoding, convolutional encoding, and interleaving algorithms are defined in the STARLink Ground Subsystem Internal Interface Control Doument.

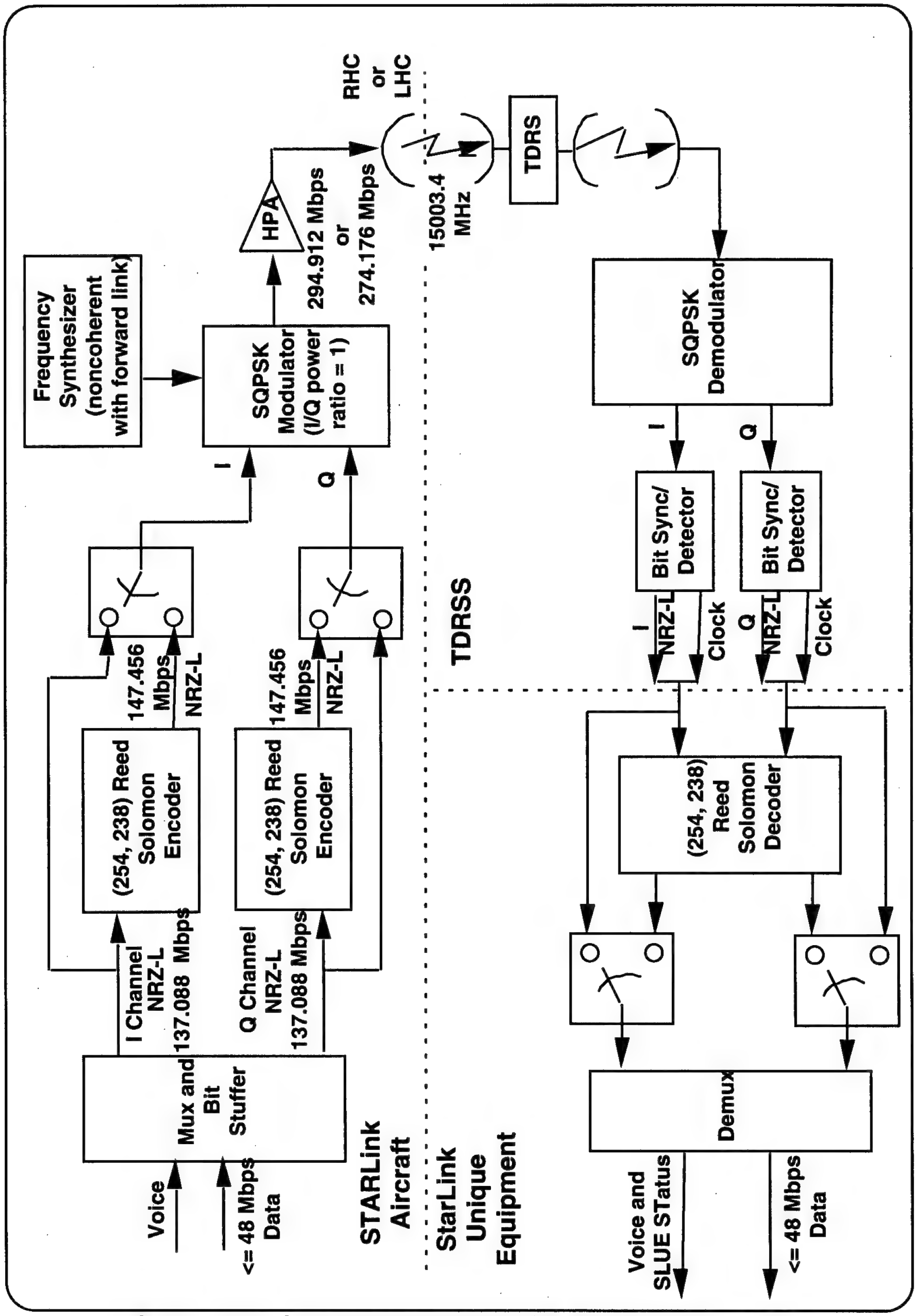


Figure 4-2 STARLINK-to-TDRSS KSA Return Link

4.3.3 Return Link Baseband Signal Parameters

This section describes the return signal processing by the SLUE, which is transparent to TDRSS. The SLUE shall process the high-rate return link data at either a 274.176 Mbps rate without Reed Solomon encoding or a 294.912 Mbps rate with Reed Solomon coding. The 274.176 Mbps signal consists of two channels, each at a 137.088 Mbps rate. The 294.912 Mbps signal consists of two channels, each at a 147.456 Mbps rate. The signal format is NRZ-L. The SLUE will despread and Reed Solomon decode, if necessary, the return signal, as well as extract the data stream from the frame sequence. It will also deinterleave and convolutionally decode the 21.42 Mbps data stream. Figure 4-3 shows the link hierarchy for the 274.176 Mbps return signal.

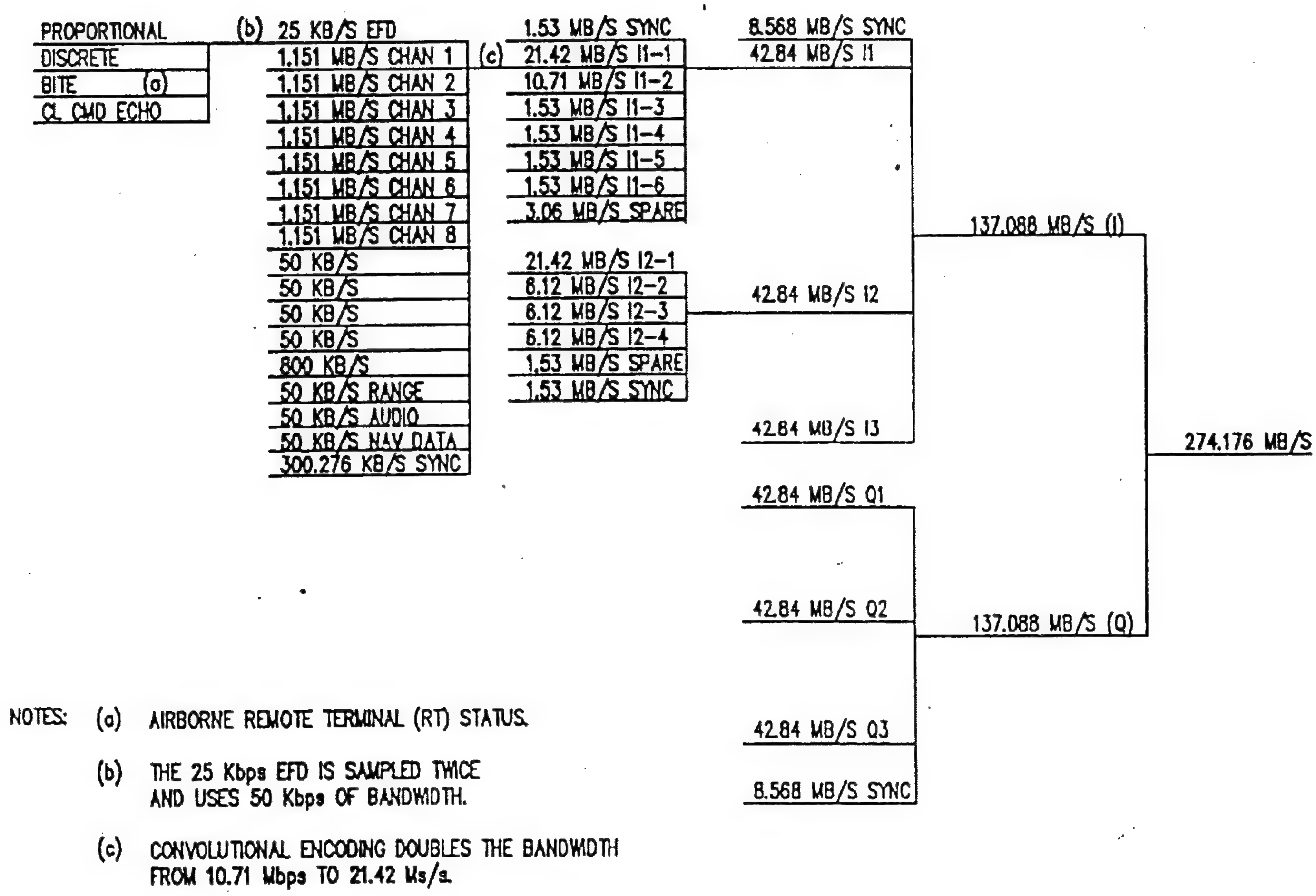


Figure 4-3 Link Hierarchy for the 274.176 Mbps Return Signal

4.3.3.1 Frame Sequence

The KSA forward link will use the following frame sequence:

S123123123123123

where S=Sync at a rate of 8.568 Mbps

1 = 42.84 Mbps (I1 or Q1)

2 = 42.84 Mbps (I2 or Q2)

3= 42.84 Mbps (I3 or Q3)

The I and Q data channels will be searched for alternating 7 bit synchronization codes. Loss of the I channel synchronization code shall disable the I channel clock. Loss of the Q channel synchronization code shall disable the Q channel clock.

4.3.3.2 Signal Processing of the 21.42 Mbps Data Stream

The 21.42 Mbps data stream will be deinterleaved using an algorithm based on a 64x64 matrix, 1 bit wide and 4096 bits long. After deinterleaving, the 21.42 Mbps data stream will be rate 1/2 convolutionally decoded with a constraint length of 7.

4.4 Radio Frequency Characteristics

4.4.1 General

This paragraph defines characteristics of the RF signals and RF signal processing in the STARLink and the TDRSS which affect the performance of the RF link.

4.4.2 Carrier Modulation/Demodulation

4.4.2.1 KSA Forward Link

The KSA forward link will use BPSK modulation (as shown in Figure 4–1).

4.4.2.2 KSA Return Link

The KSA return link will use SQPSK modulation (as shown in Figure 4–2). The data on the Q channel will be delayed one-half bit period with respect to the I channel, and the Q channel carrier will be 90 degrees out of phase with respect to the I channel (I leading Q). In addition, the I/Q power ratio will be 1:1.

4.4.3 Spread Spectrum

Spread spectrum using PN codes is transparent to TDRSS on both the forward and return links.

4.4.4 Signal Acquisition and Tracking

4.4.4.1 KSA Forward Link

The SNR required to achieve acquisition with a 90% probability is 23 dB-Hz. The STARLink can acquire a signal with a maximum frequency offset of ±71 kHz. The signal acquisition time is 0.6 seconds.

The SNR required to achieve tracking is 20 dB-Hz. The Mean Time Between Cycle Slips (MTBCS) is 100 microseconds. The STARLink can track a signal with a maximum frequency offset of ±120 kHz.

4.4.4.2 KSA Return Link

The TDRSS will acquire the return link within 11 seconds (10 seconds for autotrack acquistion with 99% probability when enabled and 1 second for signal acquisition with 90% probability) provided:

1. The received power (Prec) at TDRS is as shown in Table 4-2 plus the additional degradation due to the user constraint loss and polarization loss.
2. The velocity, acceleration, and jerk of the STARLink do not exceed 12 km/sec, 15 m/sec^2, and 0.02 m/sec^3, respectively, during coherent mode operations.
3. The POCC defined spacecraft transmit frequency for noncoherent operations is accurate to within ±5 kHz. (The acquisition time is increased to 3 seconds for a frequency uncertainty within ±20 kHz.)
4. The user spacecraft angular velocity is less than 0.0135 degree/second when the TDRS autotrack is enabled.

4.4.5 Doppler Compensation/Correction

The maximum STARLink velocity is 0.206 km/sec, which causes a maximum doppler shift of 9.4 kHz. Since this is well below the STARLink acquisition and tracking range, doppler compensation is not required. However, the TDRSS ground terminal can provide continous doppler compensation of the forward link transmitted carrier for velocities less than 12 km/sec. For velocities less than 12 km/sec and accelerations less than 15 m/sec^2, the accuracy of the user receive signal is E, where E = 500 x acceleration + 734 Hz.

STARLink state vectors will be provided to the ground terminal before each mission. Updated state vectors will be sent to the ground terminal as needed depending upon the flight path.

4.4.6 Forward Link RF Signal Characteristics

Table 4-3 defines the characteristics of the KSAF RF signal transmitted by TDRS to the STARLink. The definitions of these signal constraints are provided in STDN 101.2, Rev 7.

Table 4-3 Forward Link RF Signal Characteristics

Parameter	KSA
TDRS Signal EIRP	46.5 dBW during normal mode 40 dBW during autotrack acquisition
Modulator phase imbalance (BPSK only) (peak)	± 3 deg
Modulator gain imbalance (peak)	± 0.25 dB
Data Asymmetry (peak)	± 3%
Data transition time (90% of initial state to 90% of final state)	≤ 5% of bit duration
Phase nonlinearity (peak)	± 0.15 radian over ± 17.5 MHz
Gain flatness (peak)	± 0.8 dB over ± 17.5 MHz
Gain slope (peak)	± 0.1 dB/MHz
AM/PM	≤ 7 deg/dB
Data bit jitter (peak)	≤1%
Spurious PM	≤ 1-deg rms
Spurious output	≥ 27 dBc
Incidental AM (peak)	≤ 2%
Phase noise • 1 – 10 Hz • 10 – 32 Hz • 32 Hz – 1 kHz • 1 kHz – 25 MHz	 ≤ 1.5 deg rms ≤ 1.5 deg rms ≤ 4.0 deg rms ≤ 2.0 deg rms

4.4.7 Return Link RF Signal Characteristics

Table 4-4 defines the user constraint characteristics of the KSAR RF signal transmitted by STARLink to the TDRSS. These signal constraints are defined in STDN 101.2, Rev 7.

The following parameters are expected values and do not meet these user constraints:

a. Modulator gain imbalance: 0.5 dB

b. Phase imbalance: 4 degrees

c. Phase Nonlinearity (peak): 7 degrees (goal)

d. Gain flatness (peak): 0.7 dB (goal)

e. Data rise time: 10% of bit time

f. Data Asymmetry: 5%

These noncompliant parameters must be compensated for by additional Prec at TDRS. The user constraint loss for these parameters is 3.2 dB, assuming that the AM/PM is 10°/dB and the gain slope is 0.05 dB/MHz.

As shown in Table 4-4, the maximum total Prec for both channels is -149.2 dBW. Table 4-2 shows that the minimum Prec for both channels with a combined data rate of 294.912 Mbps and autotrack enabled is -149.2 dBW (-153.1 dBW + 3.9 dB signals losses). Therefore, the minimum and maximum Prec values are equal. With autotrack disabled, the minimum Prec is increased 2.5 dB, so that the minimum Prec is actually 2.5 dB above the maximum Prec. With autotrack disabled and a 274.176 combined data rate, the minimum Prec is 2.2 dB above the maximum Prec. A Prec higher than the maximum Prec can cause interference to other KSA users. Therefore, whenever STARLink is the only KSA user being supported by a single TDRS, the maximum Prec may be increased by up to 5 dB and the SN will guarantee support. However, when the same TDRS supports another KSA user simultaneously, STARLink may need to limit the maximum Prec to the value shown in Table 4-4 to avoid causing interference to the other user.

4.4.8 Frequency Stability

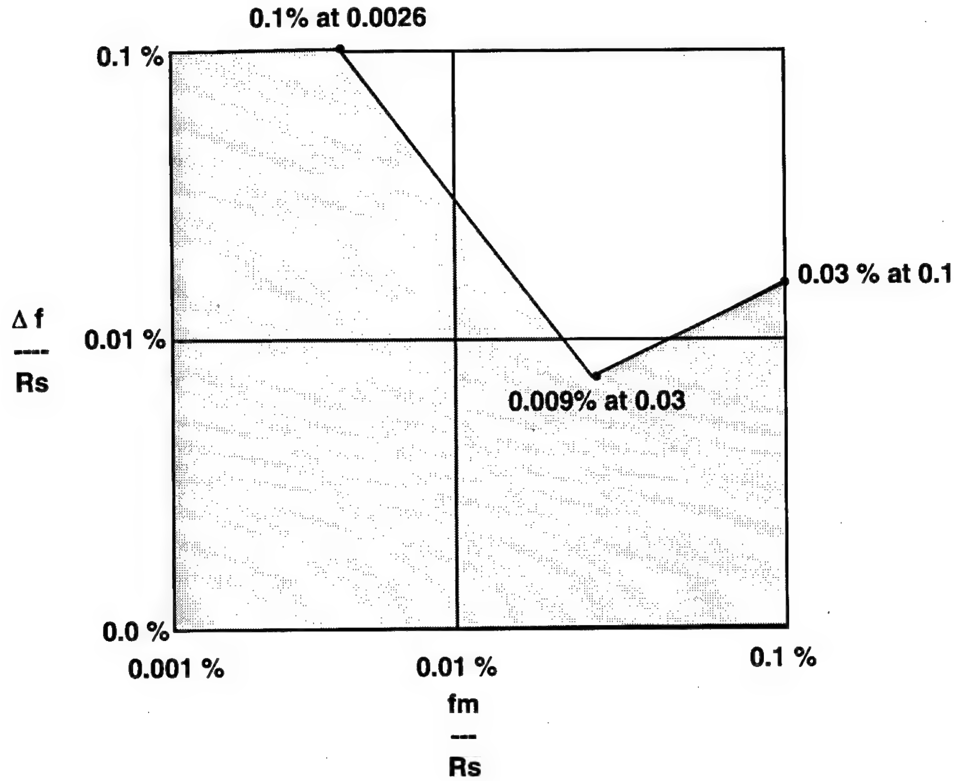
4.4.8.1 TDRSS Frequency Stability

The carrier frequency transmitted by TDRSS will have a stability of 5 $x10^{-12}$ with a 1 second average and 5 $x10^{-11}$ in the long term.

Table 4-4. Return Link Signal Parameters (User Constraints)

Parameter	KSA Requirements
Data symbol transition density	>25% for any group of 512 symbols
Maximum number of consecutive symbols without a transition on either the I or Q channel.	≤ 64
Data bit jitter	See Figure 4-4
Data asymmetry	≤ ±3%
Data risetime	≤ 5% of the bit period
Gain imbalance	± 0.25 dB
I/Q channel power ratio	≤ ± 0.4 dB from nominal
QPSK phase imbalance	90 ± 3 deg
Phase nonlinearity (applies for all types of phase nonlinearities) (peak)	≤ 3 deg over ± 80 MHz
Gain flatness (peak)	≤ 0.3 dB over ± 80 MHz
Gain slope (peak)	≤ 0.1 dB/MHz over ± 80 MHz
AM/PM	≤ 12 deg/dB
Minimum 3-dB bandwidth prior to power amplifier, DG2	>Two times max channel symbol rate
Untracked spurious PM	≤ 2 deg rms
Frequency stability (peak) • 1-second average time • 5-hour average time • 48-hour average time	 $\leq 3 \times 10^{-9}$ $\leq 1 \times 10^{-7}$ $\leq 3 \times 10^{-7}$
Incidental AM (peak) (see note) • At frequencies ≤2 kHz • At frequencies between 2 and 10 kHz • At Frequencies > 10 kHz	 ≤ 0.6% ≤ 3.0% ≤ 5.0%
Untracked phase noise (noncoherent)	≤ 2 deg rms
I/Q data skew (relative to requirements for I/Q data synchronization where appropriate) (peak)	≤ 3%
Permissible Prec variation (without reconfiguration message)	≤ 12 dB
Permissible rate of Prec variation	≤ 10 dB per sec
Maximum P_{rec}	-149.2 dBW
Axial ratio over ± 0.4 deg from boresight	≤ 3 dB

Note 1. The TDRSS design implementation may not provide the stated TDRSS KSA return service autotrack performance when Prec=Prec(minimum), and the incidental AM(peak), at frequencies < 2kHz, is close to or at 0.6 percent. For TDRSS KSA return service autotrack performance, either Prec must be increased above Prec(minimum) or the incidental AM(peak), at frequencies <2 kHz, must be more controlled.



Rs = Symbol Rate
fm = Jitter Rate
Δf = Peak Frequency Deviation

Figure 4-4 Data Bit Jitter Specification

4.4.8.2 STARLink Frequency Stability

a. The carrier transmitted by STARLink will be derived from a local oscillator that meets the frequency stability defined in Table 4–4.

b. The STARLink Program Office will ensure that the local oscillator-controlled frequency is predictable within ± 5 kHz.

4.4.9 Antenna Acquisition and Tracking

4.4.9.1 General

The STARLink-TDRS KSA return link will be initiated using one of two acquisition sequences. The baseline acquisition sequence entails the TDRS open-loop pointing in the direction of STARLink. The alternate acquisition sequence entails the TDRS autotrack pointing in the direction of STARLink.

STARLink will automatically angle track the modulated Ku-band forward-link signal transmitted from TDRS using a 32 inch steerable antenna from -15° to 85° elevation and from 0° to 360° azimuth (no wrap).

TDRSS initiates acquisition by open-loop pointing towards STARLink using the improved interrange vector contained in the vector script. The following paragraphs provide the details of the antenna acquisition sequence:

a. The STARLink Payload Operations Control Center (POCC) will provide the NCC with a pointing-vector script. This script will list the KSA antenna pointing vectors (using Type 8 format) and the time at which each vector is applicable. The POCC will also provide a predicted user operating frequency to within ±5 kHz for nominal operation, along with the other appropriate communication link configuration parameters.

b. TDRSS will configure WSC and the appropriate TDRS for the requested service. The forward and return service start time must be scheduled to occur simultaneously.

c. At the scheduled start time of the KSA forward service (t_0), TDRS will radiate an acquisition mode EIRP of 40 dBw in STARLink's direction, the signal being compatible with the forward-link signal parameters defined in Table 4–3. The forward link data stream will contain random data (no commands) until return-link acquisition is achieved. This random data will not be an alternating {0, 1} sequence. The data will consist of a random bitstream, with 50-percent transition density, until forward-link acquisition is completed. The transmit frequency will include doppler compensation unless inhibited.

d. The STARLink Ku-band antenna will point to the scheduled TDRS to an accuracy of ± 0.50 degree or, equivalently, to within 1.0 dB of its boresight gain.

e. STARLink will search for the TDRS Ku-band signal and complete antenna acquisition within 30 seconds using a spiral search of its initial uncertainty region of ±0.5 degrees. A star search pattern will then reduce STARLink's off-pointing uncertainty to ±0.22° or,

equivalently, to within 0.37 dB of its boresight gain. Immediately following indication of antenna acquisition, the STARLink autotrack and signal acquisition will be initiated.

f. Within 30 seconds of t_0, STARLink will begin radiating in the direction of TDRS with an initial signal EIRP such that P_{rec} at TDRS is < -159.2 dBW. STARLink will then increase its transmitted EIRP at a rate of no greater than 10 dB per second until the P_{rec} at TDRS reaches its final value. The final value will be greater than -149.5 dBW (-153.1 dBW plus a user constraint loss of 3.2 dB, a polarization loss of 0.2 dB, and a pointing loss of 0.5 dB), but will always be less than the maximum allowable level of -149.2 dBW. The STARLink signal parameters will comply with the constraints detailed in Table 4–4, with the exception of those parameters listed in Section 4.4.7.

g. Without TDRSS antenna autotrack: TDRS will start acquisition of the return link signal and complete carrier and bit synchronizer lock within 3.25 seconds of receipt of the signal at TDRS, provided the Prec contraints are satisfied.

   With TDRSS autotrack: TDRS will search for the Ku-band signal from STARLink and realize autotrack fine pointing within 15.25 seconds of receipt of the return signal at TDRS, provided the Prec constraints are satisifed. Simultaneously, TDRSS will start acquisition of the signal and complete carrier and bit synchronizer lock within 3.24 seconds of receipt of the return signal at TDRS. The TDRS EIRP will be 46.5 dBW after autotrack acquisition.

h. The transmission of forward link command data may begin any time after TDRSS acquires the return link signal.

4.5 Interface Characteristics Summary

The expected STARLink signal performance is provided in Appendix A. Analysis of the return signal noncompliant parameters indicates a 3.2 dB degradation of performance, which will be compensated for by an equivalent increase in STARLink transmitted EIRP over that specified by the minimum achievable data rate (ADR) equation in the Space Network Users Guide. The results show a 51.8 dB link margin for the forward signal acquisition, 6.7 dB link margin for the command channel data, 1.4 dB margin for the 274.176 Mbps return link data, 1.1 dB margin for the 294.912 Mbps return link data before Reed Solomon decoding, and 3.8 dB margin for the 294.912 Mbps return link data after Reed Solomon decoding.

Appendix A—Predicted RF Signal Performance

*** FORWARD LINK CALCULATION -- NETWORK SYSTEMS ENGINEER ANALYSIS ***

GSFC C.L.A.S.S. ANALYSIS #1 DATE & TIME: 7/11/95 15: 2:25 PERFORMED BY: L.HARRELL

USERID: STARLINK LINKID: KSAF RELAY SAT.: TDRS-East

SERVICE:	FREQUENCY:	DATA RATE:	POLARIZATION:	RANGE CASE:	NOMINAL RANGE:	RUN TYPE:
KSA	13775.0 MHz	400.000 KBPS	RCP	MAXIMUM		ICD

--COHERENT LINK

PARAMETER	VALUE	TOLERANCE	REMARKS
1. RELAY NETWORK EIRP-DBW	46.5	-	STDN 101.2
2. FREE SPACE LOSS-DB	207.6	-	NOTE B
3. POLARIZATION LOSS-DB	.2	.0	NOTE A
4. USER ANTENNA GAIN-DB	37.0	.0	NOTE A
5. USER ANTENNA POINTING LOSS-DB	.5	.0	NOTE A
6. USER PASSIVE LOSS-DB	1.5	2.0	NOTE A
7. USER RECEIVED POWER-DB	-126.3	-	SUM 1 THRU 6
8. USER COMPATIBILITY LOSS-DB	.0	.0	NOTE B
9. ATMOSPHERIC LOSS-DB	.0	*	NOTE B
10. RFI LOSS-DB	*	-	NOTE B
11. DYNAMICS LOSS-DB	*	*	NOTE B
12. USER EFFECTIVE RECEIVED POWER-DBW	-126.3	-	SUM 7 THRU 11
13. USER NOISE SENSITIVITY-DBW/HZ	-198.6	.0	NOTE A
14. USER RECEIVED-P/NO-DB-HZ	72.3	-	12 MINUS 13
15. USER REQUIRED ACQUISITION-P/NO-DB-HZ	20.5	.0	NOTE A
16. USER ACQUISITION MARGIN-DB	51.8	-	14 MINUS 15
		-2.0	SUM (NOTE C)
		-2.0	RSS
17. COMMAND TO TOTAL POWER RATIO-DB	.0	-	NOTE A
18. USER TRANSPONDER LOSS-DB	.0	.0	NOTE A
19. RECEIVED COMMAND-P/NO-DB	72.3	-	SUM 14,17,18
20. COMMAND DATA RATE-DB-HZ	56.0	-	NOTE A
21. USER RECEIVED EB/NO-DB	16.3	-	19 MINUS 20
22. USER REQUIRED EB/NO-DB	9.6	.0	NOTE A
23. EFFECTIVE USER COMMAND MARGIN-DB	6.7	-	21 MINUS 22
		-2.0	SUM (NOTE C)
		-2.0	RSS

NOTE A: PARAMETER VALUE FROM USER PROJECT - SUBJECT TO CHANGE
NOTE B: FROM CLASS ANALYSIS IF COMPUTED
NOTE C: SUM=-ABS(SUM(ABS. VALUES OF TOLERANCES))
* = NOT CONSIDERED IN THE ANALYSIS

*** RETURN LINK CALCULATION -- NETWORK SYSTEMS ENGINEER ANALYSIS ***

GSFC C.L.A.S.S. ANALYSIS #0 DATE & TIME: 7/11/95 15:10:52 PERFORMED BY: L.HARRELL

USERID: STARLINK LINKID: KSAR1 RELAY SAT.: TDRS-East RELAY GND TERM: WSGT

SERVICE:	FREQUENCY:	DATA GROUP/MODE:	POLARIZATION:	RANGE CASE:	NOMINAL RANGE:	RUN TYPE:
KSA	15003.4 MHz	DG-2 MODE-*	RCP	MAXIMUM		ICD

I CHANNEL	Q CHANNEL
DATA RATE = 147456.00 KBPS	DATA RATE = 147456.00 KBPS
MOD TYPE = SQPSK	MOD TYPE = SQPSK
DATA TYPE = NRZ-L	DATA TYPE = NRZ-L
CODING = 0----UNCODED	CODING = 0----UNCODED

PARAMETER	WORST CASE RUN		TOLERANCE		REMARKS
	I CHAN.	Q CHAN.	I CHAN.	Q CHAN.	
1. USER TRANSMITTER POWER-DBW	24.7	24.7	.0	.0	NOTE A
2. USER PASSIVE LOSS-DB	2.2	2.2	.0	.0	NOTE A
3. USER ANTENNA GAIN-DBI	37.8	37.8	.0	.0	NOTE A
4. USER POINTING LOSS-DB	.5	.5	.0	.0	NOTE A
5. POLARIZATION LOSS-DB	.2	.2	.0	.0	NOTE A
6. USER DATA/TOTAL POWER RATIO-DB	-3.0	-3.0			NOTE A
7. FREE SPACE LOSS-DB	208.4	208.4			NOTE B
8. RELAY NETWORK RECEIVED POWER-UNITY GAIN-DBW	-151.8	-151.8			SUM 1 THRU 7
9. USER CONSTRAINT LOSS-DB	3.2	3.2	.0	.0	NOTE B
10. OTHER LOSSES-DB	.0	.0	.0	.0	NOTE C
11. RFI ENVIRONMENT LOSS-DB	.0	.0			NOTE D
12. DEGRADED EFFECTIVE POWER-UNITY-DBW	-155.0	-155.0			SUM 8 THRU 11
13. REQUIRED EFFECTIVE POWER-UNITY-DBW	-156.1	-156.1			STDN 101.2
14. EFFECTIVE USER MARGIN-DB	1.1	1.1			12 MINUS 13
			.0	.0	SUM
			.0	.0	RSS

NOTE A--FROM REFERENCE-SUBJECT TO CHANGE BY USER
NOTE B--FROM CLASS ANALYSIS
NOTE D--FROM CLASS ANALYSIS

NOTE C--FROM CLASS ANALYSIS IF COMPUTED

CONTAINS		
	DYNAMICS LOSS-DB	= * , *
	ATMOSPHERICS LOSS-DB	= .00 , .00
	MULTIPATH LOSS-DB	= * , *

*--NOT APPLICABLE OR NOT COMPUTED

RETURN LINK COMPATIBILITY CHECK:

....The link is ESSENTIALLY COMPATIBLE....

*** RETURN LINK CALCULATION -- NETWORK SYSTEMS ENGINEER ANALYSIS ***

GSFC C.L.A.S.S. ANALYSIS #0 DATE & TIME: 7/11/95 15:10:52 PERFORMED BY: L.HARRELL

USERID: STARLINK LINKID: KSAR1 RELAY SAT.: TDRS-East RELAY GND TERM: WSGT

SERVICE:	FREQUENCY:	DATA GROUP/MODE:	POLARIZATION:	RANGE CASE:	NOMINAL RANGE:	RUN TYPE:
KSA	15003.4 MHz	DG-2 MODE-*	RCP	MAXIMUM		ICD

I CHANNEL	Q CHANNEL
DATA RATE = 147456.00 KBPS	DATA RATE = 147456.00 KBPS
MOD TYPE = SQPSK	MOD TYPE = SQPSK
DATA TYPE = NRZ-L	DATA TYPE = NRZ-L
CODING = 0----UNCODED REED SOLOMON	CODING = 0----UNCODED REED SOLOMON

PARAMETER	WORST CASE RUN I CHAN.	WORST CASE RUN Q CHAN.	TOLERANCE I CHAN.	TOLERANCE Q CHAN.	REMARKS
1. USER TRANSMITTER POWER-DBW	24.7	24.7	.0	.0	NOTE A
2. USER PASSIVE LOSS-DB	2.2	2.2	.0	.0	NOTE A
3. USER ANTENNA GAIN-DBI	37.8	37.8	.0	.0	NOTE A
4. USER POINTING LOSS-DB	.5	.5	.0	.0	NOTE A
5. POLARIZATION LOSS-DB	.2	.2	.0	.0	NOTE A
6. USER DATA/TOTAL POWER RATIO-DB	-3.0	-3.0			NOTE A
7. FREE SPACE LOSS-DB	208.4	208.4			NOTE B
8. RELAY NETWORK RECEIVED POWER-UNITY GAIN-DBW	-151.8	-151.8			SUM 1 THRU 7
9. USER CONSTRAINT LOSS-DB	3.2	3.2	.0	.0	NOTE B
10. OTHER LOSSES-DB	.0	.0	.0	.0	NOTE C
11. RFI ENVIRONMENT LOSS-DB	.0	.0			NOTE D
12. DEGRADED EFFECTIVE POWER-UNITY-DBW	-155.0	-155.0			SUM 8 THRU 11
13. REQUIRED EFFECTIVE POWER-UNITY-DBW	-158.8	-158.8			
14. EFFECTIVE USER MARGIN-DB	3.8	3.8			12 MINUS 13
			.0	.0	SUM
			.0	.0	RSS

NOTE A--FROM REFERENCE-SUBJECT TO CHANGE BY USER
NOTE B--FROM CLASS ANALYSIS
NOTE D--FROM CLASS ANALYSIS

NOTE C--FROM CLASS ANALYSIS IF COMPUTED

CONTAINS DYNAMICS LOSS-DB = * , *
ATMOSPHERICS LOSS-DB = .00 , .00
MULTIPATH LOSS-DB = * , *

*--NOT APPLICABLE OR NOT COMPUTED

RETURN LINK COMPATIBILITY CHECK:

....The link is ESSENTIALLY COMPATIBLE....

*** RETURN LINK CALCULATION -- NETWORK SYSTEMS ENGINEER ANALYSIS ***

USERID: GSFC C.L.A.S.S.. ANALYSIS #0 STARLINK   LINKID: KSAR2   DATE & TIME: 7/11/95 15:10:52   RELAY SAT.: TDRS-East   PERFORMED BY: L.HARRELL   RELAY GND TERM: WSGT

SERVICE:	FREQUENCY:	DATA GROUP/MODE:	POLARIZATION:	RANGE CASE:	NOMINAL RANGE:	RUN TYPE:
KSA	15003.4 MHz	DG-2 MODE-*	RCP	MAXIMUM		ICD

I CHANNEL

DATA RATE = 137088.00 KBPS
MOD TYPE = SQPSK
DATA TYPE = NRZ-L
CODING = 0----UNCODED

Q CHANNEL

DATA RATE = 137088.00 KBPS
MOD TYPE = SQPSK
DATA TYPE = NRZ-L
CODING = 0----UNCODED

PARAMETER	WORST CASE RUN		TOLERANCE		REMARKS
	I CHAN.	Q CHAN.	I CHAN.	Q CHAN.	
1. USER TRANSMITTER POWER-DBW	24.7	24.7	.0	.0	NOTE A
2. USER PASSIVE LOSS-DB	2.2	2.2	.0	.0	NOTE A
3. USER ANTENNA GAIN-DBI	37.8	37.8	.0	.0	NOTE A
4. USER POINTING LOSS-DB	.5	.5	.0	.0	NOTE A
5. POLARIZATION LOSS-DB	.2	.2	.0	.0	NOTE A
6. USER DATA/TOTAL POWER RATIO-DB	-3.0	-3.0			NOTE A
7. FREE SPACE LOSS-DB	208.4	208.4			NOTE B
8. RELAY NETWORK RECEIVED POWER-UNITY GAIN-DBW	-151.8	-151.8			SUM 1 THRU 7
9. USER CONSTRAINT LOSS-DB	3.2	3.2	.0	.0	NOTE B
10. OTHER LOSSES-DB	.0	.0	.0	.0	NOTE C
11. RFI ENVIRONMENT LOSS-DB	.0	.0			NOTE D
12. DEGRADED EFFECTIVE POWER-UNITY-DBW	-155.0	-155.0			SUM 8 THRU 11
13. REQUIRED EFFECTIVE POWER-UNITY-DBW	-156.4	-156.4			STDN 101.2
14. EFFECTIVE USER MARGIN-DB	1.4	1.4			12 MINUS 13
			.0	.0	SUM
			.0	.0	RSS

NOTE A--FROM REFERENCE-SUBJECT TO CHANGE BY USER
NOTE B--FROM CLASS ANALYSIS
NOTE D--FROM CLASS ANALYSIS

NOTE C--FROM CLASS ANALYSIS IF COMPUTED

CONTAINS DYNAMICS LOSS-DB *
ATMOSPHERICS LOSS-DB .00
MULTIPATH LOSS-DB .00

*--NOT APPLICABLE OR NOT COMPUTED

RETURN LINK COMPATIBILITY CHECK:

....The link is ESSENTIALLY COMPATIBLE....

Glossary

ADR	achievable data rate
AM	amplitude modulation
BER	bit error rate
bps	bits per second
BPSK	binary phase shift-key
BSR	bit slippage rate
dB	decibel
dBc	decibel relative to carrier level
dBW	decibel relative to 1 watt
deg	degree
DG-2	Data Group 2
DMR	detailed mission requirements
EIRP	effective isotropic radiated power (dBw)
E_b/N_o	bit energy-to-noise spectral density ratio (dB-Hz)
F	transmit carrier frequency (Hz)
f	jitter frequency amplitude
f_d	Doppler frequency
f_m	jitter frequency rate
forward link	link from ground terminal through TDRS to user
FVT	Flight Vehicle Terminal
GHz	gigahertz (1000 MHz)
GSFC	Goddard Space Flight Center
GSTDN	Ground Spaceflight Tracking and Data Network
HPA	high-power amplifier
Hz	hertz
I channel	in-phase data channel (0- and 180-degree phase) modulation of reference carrier

ICD	interface control document
kbps	kilobits per second
kHz	kilohertz
km	kilometer
KSA	Ku-band single access
LC	Link Controller
LHC	left-hand circular (polarization)
Mbps	megabits per second
MHz	megahertz
MTBCS	Mean Time Between Cycle Slips
NASA	National Aeronautics and Space Administration
Nascom	NASA Communications
NRZ-L	nonreturn to zero level
nsec	nanosecond(10^{-9})
OBC	onboard computer
PM	phase modulation
POCC	Payload Operations Control Center
P_{rec}	received signal power (dB)
P_{rec}/N_o	received signal power-to-noise spectral density ratio (dB-Hz)
psec	pico second (10^{-12})
PSK	phase shift-key
Q channel	quadrature data channel ($\pm$ 90-degree phase modulation of reference carrier)
QPSK	quadriphase shift-key
range channel	forward-link subdivision used for transferring pseudorandom noise code used for two-way range measurement
return link	link from user through TDRS to ground terminal
RF	radio frequency
RFI	radio frequency interference
RHC	right-hand circular (polarization)

rms	root-mean-square
SA	single access
SLUE	STARLink Unique Equipment
SP	STARLink Program
SQPSK	staggered quadriphase shift-key
SQPSK modulation	quadriphase process in which data bits (symbols if convolutionally encoded) of Q channel are delayed one-half bit period (one-half symbol period if convolutionally encoded) relative to I channel
STDN	Spaceflight Tracking and Data Network
STGT	Second TDRSS Ground Terminal
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TTL	Transistor-Transisitor Logic
WSC	White Sands Complex
WSGT	White Sands Ground Terminal

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